FROST-CONTROL PRACTICES AND THE PROSPECTIVE USE OF ANTHRACITE

BY J. D. CLENDENIN

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SUMMARY AND CONCLUSIONS

Systematic practices for protecting crops from frost damage began in the United States more than 40 years ago when the Weather Bureau Fruit-Frost Warning Service was organized; however, various practices employed in frost protection are centuries old.

Although there are areas where little doubt exists as to whether protection is needed, there are also circumstances where there is some doubt as to the need for frost protection. Many factors influence this, including not only critical temperatures but also the maturity dates of the crops relative to marketing. Critical temperatures for frost damage to trees, plants, blossoms, and fruits vary with weather, plant variety and nutrition, and stage of growth. In the case of truck crops, a single night of protection from frost injury might yield big dividends with a variety of sweet corn or tomato that matures early while price is high yet be worth very little with a midseason or late-maturing variety. Consequently, it is the individual grower who must decide whether to use frost-protective measures on the basis of his returns, the quantity and quality of his crop, the marketing situation, the sensitivity of his crops to frost damage, and the frequency of damaging frost in his area.

Three general principles, namely, adding heat, conserving heat, and mixing or stirring the air, are utilized as frost protection in the United States. The principal methods in use are combustion of fuel in open fires or small heaters distributed throughout the plot to be protected; sprinkling with water from an installed irrigation system; covering with hot tents, lath screens, or other shelters; and a combination of wind machines and heaters. Each has been found effective or helpful in certain areas, but, in general, artificial methods must supplement natural methods of control or natural sources of heat. If possible, orchard plantings are arranged to take advantage of natural air drainage.

Proper heating will give effective protection from frosts, but it will not give protection from a general cold wave or freeze. In general, heating cannot be expected to raise the temperature over 8° or 10° F. under ideal conditions, and a rise of 5° is more likely to be all that can be obtained. Plantings located so that they are exposed frequently to temperatures so low that an increase of 5° to 8° F. will not protect them from injury present a problem that heating will not solve. A grower who has to heat a considerable acreage of his orchard to get a crop of fruit is at a distinct disadvantage in competing with the grower who does not have this added expense, for it is the occasional orchard where heating will be profitable, rather than the general run of orchards.

Heating finds limited use in protecting crops other than citrus and deciduous tree fruits. It is an expensive procedure today, with total heating costs of about $3-1/2 to $4 per acre-hour; the fuel cost may run from one-quarter, or less, to well over one-half the total cost. Growers are making every effort to keep the use of heat to a minimum. Heaters are not fired until the last possible moment that will still give time enough for protection; this requires accurate measurement of temperatures at the level of the crop or planting. Wind machines are being employed more extensively to mix any warm air overhead with cold air near the ground, thereby reducing the supplemental heat requirement. In California, the cost of using wind machines with some heaters has been found to be about one-fifth the cost of heaters alone. The method, however, affords limited protection but is generally accepted as the economical system for California's usual frost conditions.

Sprinkling with water, using an irrigation system, has been found to protect low-growing crops, such as strawberries and truck effectively, but substantial quantities of water are necessary, as the flow of water, though not necessarily large, must usually be continued without interruption until after the temperature has risen above freezing and ice on plants has disappeared. Sprinkling has been used occasionally with some deciduous fruits during blossoming when formation of ice on branches does not lead to damage. In some areas where marketing and cultural conditions warrant, low-growing plants are covered with paper tents, such as Hotkaps, or lath or cloth screens.

These artificial frost-protection measures do not find widespread use in the United States, although they assume a degree of significance in several widely separated areas, are used occasionally in others, and show some decline in use in still others. This change is occurring principally because heating, the method that proved most effective in the past, is no longer economical, except under special circumstances or where its use is qualified with the condition that the number of firings be kept to a minimum. There is an expressed need for an effective, practical, and economical method of protection from frost damage. Investigations reported as early as 1939 have indicated some of the possibilities for spray or other applications of plant-growth regulators or special compositions to control or reduce damage from frost. If this development can be practiced as successfully as has the use of growth regulators for weed killers and defoliants, it points in the direction of decreased use of heating in the years ahead.

Current estimates of the use of frost-protective measures reveal that in New Jersey irrigation sprinkling is used on about one-quarter (or approximately 600 acres) of the total strawberry acreage, which amounted to approximately 2,400 acres in 1949. In Michigan half of the nearly 10,000 acres currently in strawberries and 10 percent (or approximately 11,000 acres) of the total acreage of vegetables harvested for sale, which amounted to about 110,000 acres in 1949, are being protected from frost by water aprinkling. In Florida a large number of truck farmers employ the same method, but in New York and the other Northeastern States only a small and undetermined number use this method of protection. In New York, New Jersey, and Pennsylvania, a very few growers use or have tried sprinkling with water as a frost deterrent when orchards and some small fruits are in blossom. In Michigan an estimated 20 percent of the acreage in early vegetable crops are covered with hot tents or Hotkaps to protect them from frost damage. Elsewhere in the Northeastern States, covering finds more limited use. In New York, hot tents are used for perhaps 1 to 2 percent of plantings of vegetables harvested for sale in some areas. Covering is used in Florida, also, to protect vegetable crops.

Heating is little used in the Northeastern States to protect against damage from frost. Two percent of the tree-fruit acreage in Michigan, which amounted to a total of 226,000 acres of trees of all ages in 1949, is heated. Heat has been used in the past to protect citrus groves in Florida, but its use has been declining in recent years because of the low return on the fruit, which, in the 1952-53 season, amounted to an average of about $266 per acre of total citrus. Some truck farmers in Florida are reported to be employing heating for frost protection; however, the high cost of heating raises the question of whether it is economically justified, despite an average return of about $514 per acre of total truck crops during the 1951-52 season.

Of the nearly 320,000 acres of California citrus in 1938, about 3 percent were equipped with solid-fuel heaters and 26 percent with oil heaters, or about 10 percent of the heater-equipped acreage used solid fuel. Since then, available evidence points to a considerable decrease in the use of heating as the sole means of frost protection and to virtual abandonment of solid-fuel heaters. For example, protection and to virtual abandonment of solid-fuel heaters. For example, protection of California citrus groves from frost damage is estimated to be worth an average annual expenditure of over $1 million or approximately 3/4 to 1-1/4 percent of the nearly $128 million total value of citrus in 1952. In the same year, when the average return was about $456 per acre of total citrus (280,000 acres), this expenditure would be equivalent to about $3-1/2 to $6 per year per acre of total citrus, which would provide approximately 1 to 2 hours of protection, using heaters alone, at today's costs (approximately $3-1/2 to $4 per acre-hour). Thus, to provide as little as 10 hours of heating per year, which may be enough in some instances, only about 10 percent, or 28,000 acres, of the 1952 acreage of total citrus could be protected by heating. However, since the wind machine and heater combination is reported to cost one-fifth as much to operate as heaters alone, this combination system would permit a fivefold increase, or 50 hours of protection per year, on the 28,000 acres and fewer than 50 hours on a larger acreage for the approximate annual expenditure cited.

Only in Washington, where average returns were around $945 per acre in tree fruits in 1950, has heating been increasing. Since 1940, when 2 percent of the acreage was heated, the heated acreage has risen to 5 percent of 97,415 acres in 1950 and to 15 percent in 1954. This increase is attributed, largely, to increased interest in varieties of fruits that bring high returns but are more sensitive to frost damage and to a cycle of colder seasons since 1950. In this State, solid-fuel (briquet) heaters have been used quite extensively; oil heaters find widespread use today.

Because the underlying purpose of this investigation has been to evaluate the present and future prospects for Pennsylvania anthracite for use in solid-fuel, frost-control heaters, an examination of the general field of frost-control problems and measures employed, as well as the part played by heating, has been a necessary step before proceeding to a more detailed picture of the role that might be developed for anthracite.

Solid-fuel heaters of the salamander type are practical in frost-control heating and have the advantages of low investment cost, smokeless operation when naturally smokeless fuels, such as anthracite, are used, and heating periods are of reasonable length. They are most useful in localities where temperatures are relatively steady. However, when atmospheric conditions are often unsteady, with large and frequent fluctuations of temperature, exclusive use of solid fuel is impractical because solid-fuel heaters of this type are not flexible enough. Solid-fuel heaters can be used in conjunction with oil heaters if the two types are placed in alternate positions in the plot to be protected, with the solid-fuel heaters, or both, used under steady or more severe conditions, and the oil heaters alone used under unsteady conditions or conditions of small heat demand. This complementary use of solid-fuel heaters should lower equipment investment costs and carrying charges and, during longer periods of high and steady heat demand, may result in decreased total-fuel costs.

Approximate heat requirements for effective protection of crops from frost damage have been investigated previously and estimates made, using fuel-consumption figures from field operations. It is generally accepted that a large number of small fires results in more effective use of the heat than a small number of large fires. The ranges of heat demand were found to be approximately 2 to 4 million B.t.u. per acre per hour and about 2 to 7 million B.t.u. per acre per firing (for 10 to 19 firings per year), depending upon temperature, weather, atmospheric conditions, size of plot heated, variety and maturity of crop, and type of heater. Thus, with heat requirements known, ignition- and burning-rate tests on Pennsylvania anthracite in a salamander heater were adequate to reveal the characteristics of this fuel pertinent in frost-control heating. Tests were conducted at Schuylkill Haven, Pa., in a 14-inch-diameter, bottom-fired salamander heater equipped with a simple grate, using both free- and hard-burning varieties of anthracite as fuel. It was found that, with no further attention after lighting, both varieties of this fuel in the Stove size (2-7/16 by 1-5/8 inches) burned at rates of 4 pounds per hour, and above, for upward of 3 to more than 8 hours, depending upon the total amount of fuel charged to the heater. The free-burning variety was kindled with ease and would attain average maximum burning rates of 10 pounds per hour within 30 to 45 minutes after lighting, whereas the hard-burning variety was much slower and more difficult to ignite, with 1-1/2 hours elapsing after lighting before the average maximum burning rate of 7 pounds per hour was reached. The burning rate of Nut size (1-5/8 by 13/16 inches), hard-burning anthracite was much the same as that for the Stove size. Top firing of neither variety was satisfactory.

In evaluating the present and future prospects for anthracite in frost-control heating, it is helpful to examine factors of fuel cost, using this fuel under conditions that might exist in practice. For example, if it is assumed that 3-1/2 million B.t.u. per acre per hour are sufficient to protect a plot when the lowest temperature is 28° F., anthracite of 13,000 B.t.u. per pound and of a size suitable for solid-fuel heaters must be available for less than $14.90 per ton, delivered, if the heater fuel cost is not to exceed $2 per acre per hour. Assuming equivalent release of heat from the fuel in this application, 140,000-B.t.u. heater oil must sell for not more than 8 cents per gallon if the heater fuel cost is not to exceed the $2 figure.

As suggested earlier, the extent to which frost-control heating is practiced within the primary anthracite-marketing area is small, and the probability of any significant increase in this practice within this area is not great, for reasons mentioned previously. Nevertheless, some areas and localities within and adjacent to the primary anthracite-marketing area may warrant limited but well-planned efforts at developing this very special market. Individual growers should have some tender crops, special market conditions, or plantings in low, cold spots that would justify heating, and anthracite could probably be used with a smaller investment in equipment and somewhat lower fuel costs than for other fuels. Likewise, supplying bulk or bagged heater fuel, competitively, to those locations far removed from the Pennsylvania anthracite region may be possible in some instances by arranging with carriers who desire a return payload after hauling produce or other goods into the northeastern markets. Each area should be visited, however, to determine specific local problems, requirements, and limitations. Practices in citrus- and deciduous-fruit areas will differ. Requirements for Florida truck growers or nurserymen will come at a different time than for New Jersey or Michigan growers, and each locality has differences characteristic of cultural practices and market demands.

The possible annual tonnage that might be used in more or less regular frost-control heating within the United States has been computed from estimates of heated acreage and the range of approximate heat requirements of 22 to 68 million B.t.u. per acre per year (0.85 to 2.62 tons of anthracite, at 13,000 B.t.u. per pound) for protection by heating alone. A probable maximum of about 76,000 acres,[2] or up to 68,000 to 208,000 tons of anthracite annually, depending upon weather conditions and other factors, might be used as heater fuel if anthracite were the sole fuel available.

In the light of present knowledge of heating and present cultural practices, 100,000 acres, or up to 85,000 to 262,000 tons of anthracite (0.85 to 2.62 tons per acre per year), might be considered as the limit of the annual market for anthracite as frost-control fuel. This would be based on the 76,000 acres cited above plus, at most, 24,000 acres consisting of: (1) An undetermined, but small, acreage of Florida truck that is heated, which may amount to 3,000 to 6,000 acres (1 to 2 percent of 309,000 acres in 1951-52); (2) some fruit or truck farmers within or adjacent to the anthracite-marketing area who may need heat occasionally and would equip themselves to use anthracite; (3) possibly a few orchards in Oregon; and (4) miscellaneous nurserymen or growers of ornamentals, principally in the south, who need heat now and then for outdoor plantings.

In conclusion, the overall picture of the prospective use of Pennsylvania anthracite as frost-control heater fuel shows few signs of its being more than a small, marginal market that promises to be far more seasonal and far more dependent upon weather and climatic factors than the industrial fuel market and the domestic, commercial, school, greenhouse, chicken brooder, and similar heating markets. The quantity of fuel used in frost-control heating is determined on the basis of hours of use in a season rather than days, weeks, or months, as with other types of heating.

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[2] Consists of 4,500 acres of deciduous fruits in Michigan; 14,600 acres of deciduous fruits in Washington; 28,000 acres of citrus in California, assuming all protection by heating; 23,400 acres of citrus in Florida; 3,000 acres of high-return fern in Florida; and 2,400 acres of deciduous fruit in Virginia.

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INTRODUCTION

In the spring of 1952, the Technical Advisory Utilization Subcommittee of the Bureau of Mines and Anthracite Research Laboratory at Schuylkill Haven, Pa., recommended an investigation of the possibilities for using Pennsylvania anthracite as fuel in supplying heat to prevent or control frost damage in orchards, nurseries, and truck farms. This had appeal because anthracite is a smokeless fuel, and a large part of the demand may occur when the regular domestic heating season in the primary anthracite marketing area is tapering off.

As a result, various organizations, agencies, and individuals were contacted for information on past and current work, on the problem of frost damage and the need for and methods of control, and the extent of investigations and frost-control practices in Massachusetts, New York, New Jersey, Pennsylvania, Michigan, Georgia, Alabama, Florida, California, Washington, and Oregon. These States cover most of the areas where frost poses a problem to commercial growers. Frost-control measures are used or could be used to a limited extent in other areas, also. Except for Virginia, Maryland, and Delaware, however, these other areas are not mentioned in this report because the information presented here delineates considerations and practices in frost control in sufficient detail to allow an evaluation of possibilities for the anthracite industry.

The purpose of this report is fourfold: (1) To place before the anthracite industry summary information and sources for more detailed information on frost-control work, if desired; (2) to emphasize economic considerations, as well as technical factors; (3) to bring to the attention of potential users the characteristics of Pennsylvania anthracite having possible significance in orchard heating;

and (4) to appraise the prospects for anthracite as fuel in frost-control heating, in particular, and frost-protective measures, in general, in order to evaluate the present and future prospects for heating as a method of protecting crops from frost damage.

This preliminary investigation has revealed that enough information is already available on technical and economic aspects of frost-control heating to permit individual companies in the anthracite industry to take any steps that management may see fit toward developing this market. Various frost-protection practices are centuries old, and more than 50 reports and published papers have appeared since systematic frost-protection practices began in this country more than 40 years ago when the Weather Bureau Fruit Frost-Warning Service was organized. Active investigations of heating and related problems in frost control have been centered in California and the Pacific Northwest, where work began before 1920; in Florida, where studies were in progress in the early thirties; and in Michigan, where work was in progress in the early forties. Water sprinklers connected to irrigation systems have been used extensively to protect low-growing crops, and this method has been studied both experimentally and in the field. Paralleling these investigations, the usefulness of spray applications of plant-growth regulators to control or reduce frost damage to fruits and plants has been under study in the United States, Canada, and abroad for more than a decade.

METHODS OF PREVENTING OR CONTROLLING DAMAGE FROM FROST

Ten methods of frost control or prevention are listed in table 1. Each one utilizes, either naturally or artificially, one or more of the following principles: (1) Heat conservation; (2) mixing or stirring the air; (3) adding heat; and (4) regulating plant growth or nutrition. Of the methods listed in table 1, only those in which heat is conserved or added and the air is stirred or mixed have proved generally satisfactory or are in widespread use. Other methods are being developed, have been abandoned, or are used only in limited areas.

Where possible frost-resistant strains of strawberries are being planted, instead of employing frost-control methods with less resistant strains. During the spring frost in southwestern Michigan in May 1954, virus-free Premier strawberry plants showed remarkable resistance to freezing temperatures. With the temperature at 29° F. or lower, only about 5 percent of the flowers and buds of this variety were frozen, and the remainder appeared to be in excellent condition. Blossoms and buds of adjacent everbearing plants apparently were 100-percent killed (40).[3]

Irrigation sprinkling with as little as 0.15 inch of water per hour (about 4,100 gallons per hour per acre) is reported to be enough to prevent frost damage (40). From a practical standpoint, however, it is better to increase the sprinkling rate up to at least 0.25 inch of water per hour (about 6,850 gallons per hour per acre) to secure even distribution, using rather high pressure and correspondingly small tip sizes so as to get enough overlap between sprinklers.[4] Because ice was observed to form in the course of sprinkling, it is probable that much of the protection from sprinkling comes from heat released when the water freezes, because this amounts to about 1,200 B.t.u. per gallon at 32° F. For example, assuming equilibrium conditions, it is estimated that enough heat would be released by freezing 500 gallons of water per hour per acre, about one-eighth of the above sprinkling rate, to raise the air temperature from 27° to 33° F. over an area of 1 acre to a height of 100 feet. In contrast, cooling the entire 4,100 gallons per hour per acre by 10°, say from 43° to 33° F., would yield only half as much heat as by freezing the 500 gallons of water, assuming that all the sensible heat in the water were effective.

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[3] Underlined numbers in parentheses refer to citations in the bibliography at the end of this report.

[4] Letter from J. H. Mandigo, July 20, 1954.

Large-area protection by artificial cloud screening to reduce heat radiation loss to the sky is one of the oldest proposals for protection. It has been tried, using military smoke-screen generators, but the smoke-screen droplets of 0.5 to 0.6 micron diameter were found to be substantially transparent to the passage of infrared radiation, having 10 microns average wavelength, such as emitted by bodies at temperatures of 30° to 70° F., whereas, natural moisture clouds have low transmittance for the same radiation by virtue of their larger average particle diameter, which is of the order of 10 microns. Because very uniform particle size is necessary to avoid too rapid settling, the necessary large particle generators are not yet available. Because of the need for wide coverage, artificial cloud screening should be a fully cooperative venture if damage litigation is to be avoided. Besides, experiments over a quarter century have yet to place artificial cloud screening on a more economical and practical basis than heating (1, 6, 7).

It is known, too, that, if plants and vegetation can be shielded or shaded from direct rays of the sun following a frost, frost burn and damage to vegetation and plants is not nearly so severe as when the sun bears directly onto the frosted plant tissue. A bank of clouds forming in the eastern portion of the sky before sunrise on a frosty night appears to reduce the amount of low-temperature damage; similarly, great quantities of orchard-heater smoke in the air following a cold night have appeared to reduce the amount of damage (1), presumably because the crops are screened from strong sunlight throughout much of the day.

During the past 15 years, plant scientists have been investigating the possible usefulness and the limitations of sprays and other applications containing very low concentrations of the so-called plant hormones or growth-regulating substances and related compounds as means of controlling or reducing frost damage to blossoms, plants, and fruits and of promoting normal fruit development (28, 32, 33, 34, 36, 37, 38, 39, 48). This research is time consuming and, because of the specific nature of many of the growth-promoting substances, results have sometimes been contradictory, with two varieties of the same fruit responding quite differently to the same treatment. Consequently, reduction of the results of these studies to practice will not necessarily supplant heating as a means of controlling damage from frost. But, should chemical means of controlling frost damage be perfected to the same degree as chemical defoliants and weed killers, there is definite promise for a practical and economical supplementary means of controlling or lessening frost damage, which will influence the extent to which frost-control heaters will be employed.

Polyethylene packaging of Bartlett pears permits storage of the fruit so that it can compete on the fresh market with later-ripening fruit, which will affect marketing and, ultimately, cultural practices (45, 49).

FACTORS IN THE USE OF HEATERS FOR FROST PROTECTION

The main objective in heating an orchard, grove, nursery, or truck field is to raise and keep the temperature above the critical point (1, 11, 13, 16) for the particular crop.[5] It has been said that artificial efforts at frost protection do little more than supplement natural heat sources, which, by themselves, do not quite keep the minimum temperature above the danger point (6).

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[5] Letters from W. O. Johnson, June 4 and Aug. 12, 1952; Aug. 7, 1953; and June 1, 1954.

TABLE 1. - Methods of control or prevention of damage from frost and cold and general principles employed

Methods of frost control or prevention	General principles employed: Heat conservation	Addition of heat	Mixing or stirring the air	Regulation of plant growth or nutrition	Remarks; and references for more detailed information[1]
1. Use of heat to raise air temperature		X			Most common. See ref. 1, 2, 4, 5, 6, 8, 9, 10, 11, 12, 13, 18, 19, 23, 30, 41, 47.[2] [3]
2. Use of infrared energy to warm trees or plants by radiation............		X			Air temperature also increased by convection from heater. See ref. 1, 3, 5, 14, 15, 16.
3. Use of wind machines, aerial flights, or helicopter rotor to move cold air at surface of earth and take advantage of temperature inversion	X		X		Common in California; limited use in Virginia. See ref. 1, 6, 13, 17, 24, 35.[4]
4. Spraying plants with irrigation water or flooding................	X	X			Used with low-growing plants. See ref. 1, 40.[5]
5. Covering with shelters, such as Hotkaps, cloth or lath screens, etc.	X				Principally used with low-growing plants. See ref. 1, 11, 20, 29.[6]
6. Artificial cloud screening..........	X				Little used. See ref. 1, 6, 7, 25.
7. Natural air drainage................	X		X		Very important. See ref. 1, 6, 13, 31, 44.[7]
8. Soil conditioning - packing, mounding, treatment of surface.........	X				Used in some areas. See ref. 1, 5, 6, 21, 22, 46.[8]
9. Application of plant-growth regulators and/or nutrients by spraying and fertilizer drilling equipment.				X	Undergoing development and study. See ref. 13, 26, 28, 32, 33, 34, 36, 37, 38, 39, 48.
10. Combination of methods 1 and 3		X	X		Common in California.

[1] Reference numbers in the last column refer to numbers in the bibliography at the end of this report.

[2] Also letters from P. S. Harner, 1952; Otto Brown, June 23, 1952; O. C. Roberts and C. L. Thomson, June 4 and 8, 1954, respectively; W. A. Luce, Apr. 26, May 24, June 1, and June 15, 1954; W. J. Rogers, May 30, 1954; A. Van Doren, Apr. 2, 1954; F. D. Young, June 14, 1954; C. I. Robertson, July 1, 1954; J. F. Haldeman, July 6, 1954; H. H. Campbell, July 7, 1954; C. S. Bittner, June 28, 1954; W. M. Barry, July 7, 1954; T. D. Jordan, July 14, 1954; A. S. Leonard, July 30, 1954; R. F. Fletcher, Aug. 8, 1954.

[3] Information received from the California Heater Co., Pomona, Calif., and the Scheu Manufacturing Co., Upland, Calif.

[4] Also letters from J. G. Rogers, July 21, 1954; E. K. Lucas, Aug. 19, 1954.

[5] Also letters from W. O. Johnson, June 4, and Aug. 12, 1952, Aug. 7, 1953, and June 1, 1954; E. G. Christ, Apr. 24, 1952, and June 9, 1954; C. I. Robertson, July 1, 1954; H. H. Campbell, July 7, 1954; W. F. Greenawalt, July 7, 1954; T. D. Jordan, July 14, 1954; R. F. Fletcher, Aug. 18, 1954; J. H. Mandigo, July 20, 1954.

[6] Also letters from H. H. Campbell, July 7, 1954; W. F. Greenawalt, July 7, 1954; T. D. Jordan, July 14, 1954; R. F. Fletcher, Aug. 18, 1954.

[7] Also letters from J. E. Linde, Sr., and J. E. Linde, Jr., Dec. 2, 1952.

[8] Also letters from F. E. Johnstone, Jr., June 6, 1952; E. F. Savage, May 2, 1952.

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Frost protection for acreages of crops by heating should be planned to handle the most severe conditions that could occur in the locality.[6] Without adequate preparations, the loss may include not only the crop, but also heating costs that have accrued in previous firings for protection of the same crops.

Many factors influence the need, difficulty, and extent of frost-protection practices in which heaters are employed. Among these are: (1) Fuel and heater characteristics; (2) ceiling or air-temperature inversion at the earth's surface and natural cooling by radiation; (3) border effect in heating; (4) size and spacing of heaters; (5) wind and air drift; (6) local topography, soil, and atmospheric conditions; (7) critical or damaging temperatures for different varieties of trees and plants; (8) frequency, severity, duration, and time of frost or low temperatures; and (9) temperatures in the orchard or at the level of the crop subjected to frost protection.

According to published reports, nearly every type of fuel and many waste and scrap materials have been burned in heaters for frost protection. These fuels include wood, various grades of fuel oil, liquefied petroleum gas, petroleum coke, coal, coal briquets, carbon briquets, and coke from coal; no record of the use of Pennsylvania anthracite was found. Availability, cost, and amount of labor involved in firing influence choice of orchard-heating fuels for general use.

Air-temperature inversion at the earth's surface, or ceiling, is very important in frost-protection practices when heaters are used. Air-temperature inversion results when warm air from normal daytime heating forms a layer or ceiling overhead or above a layer of air that is cooled next to the earth's surface at night; being cool, the air does not rise. This is the reverse of daytime conditions, when air is heated at the earth's surface and rises. The difference in temperature between these two layers determines whether the inversion is strong or weak, and whether the ceiling is low or high. The height to which heated air rises before its temperature is in equilibrium with the surrounding air indicates the height of the ceiling.

In protecting trees and low-growing crops with heaters, the mode by which the heat energy reaches the tree or plant is significant. With low-growing truck crops, radiant heat plays an important part in maintaining a safe temperature; however, shading (3, 14) greatly influences the effectiveness of radiant heating. With trees, the relative importance of the radiant fraction depends more upon whether the ceiling is high or low, that is, whether the inversion is small or large. When the inversion is small, most of the convective heat from hot stack gases and heated air rises above the tree tops and is less effective. With these conditions, radiant heating is important. When the inversion is large, more of the convective heat is held down within the tree zone to supplement the radiant heat. Thus, a heater with a higher radiant output or operating a heater at higher temperatures to give a higher radiant output is more advantageous with smaller inversions. Furthermore, it has been concluded from tests (5) that, with a large inversion, there appears to be little choice as to type of heater but, with smaller inversions, there are definite differences in effectiveness. The bulk of experience, however, favors a large number of small fires, rather than a small number of large fires, unless the air is stirred by a propellor or rotor (1, 17).

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[6] See footnote 5.

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The importance of the ceiling or temperature inversion of the air near the earth's surface and of the use of small fires or less concentrated sources of heat was demonstrated in the course of field tests conducted in Florida in 1949 with the Evans Frostguard, a high-output, smokeless heater, which is described later. Adjacent to the Frostguard test plot, a farmer was protecting a 1-acre plot of pepper and tomato seedlings with wood fires placed around the plot and a few fires within the plot. The yound plants were saved from damage on two successive nights. Over the top of the 1-acre plot, leveling of smoke from the fires could be observed from the Frostguard plot where the minimum temperature was 25.2° F. This leveling of the smoke indicated that the warmed air from the wood fires was rising and flattening out against the top of the temperature inversion. No such leveling was noted over the Frostguard plot, which indicated that the convection from the Frostguards was so strong as to puncture the top of the inversion and allow the warmed air to escape to outer space (9).

Response to heating is most favorable on nights of large or strong inversion when the ceiling is low and is less on nights of weak inversion when the ceiling is high. The statement has been made (6) that, without a ceiling, heating is so difficult that neither heaters nor wind machines can be considered satisfactory frost-protection means where there is no warm air overhead.

Because of the border effect, or cooling at the edge or perimeter of a heated area, heat requirements per acre depend upon the size of the tract being heated. It has been stated that the border effect makes the cost of heating a single acre at least twice as the cost per acre in mass heating, but heating a 25-acre tract using about 1 million B.t.u. per hour per acre per 1° F. rise of air temperature in a 5-1/2° F. inversion comes close to ordinary practice in mass heating (6).

Cold-air drift will affect the updrift side of a heated plot and will require more heaters. Fields on adjacent or nearby sites may experience marked differences in temperature because of wide differences in air drainage. Critical or damaging temperatures for fruit trees and plants are determined by the type of fruit or plant, maturity, weather preceding the frost, the vigor of the tree, and the length of time the low temperature persists. In addition, different varieties of the same fruit often differ considerably in their susceptibility (1, 11, 16). Temperature of air surrounding low-growing crops may be appreciably lower than that of air surrounding the blossoms or fruits of adjacent trees.

It has long been known (1), and more recent investigations (6) have shown, that the condition of the soil - namely, packing, moisture, and cover vegetation - influences frost formation and air temperature near the ground. These factors influence heat absorption by the soil during the day and heat loss at night, but the degree to which these factors exert a significant influence varies greatly with different conditions.

Depending on the character of the air mass above the earth, nocturnal radiation cooling from the ground and vegetation to space normally amounts to about 2/3 to 1-1/10 million B.t.u. per acre per hour and is substantially constant on clear nights; it can be interpreted approximately in terms of the difference between tree-top and equivalent sky temperatures. If frost-control measures are to be effective, this loss must be supplied by heating or be controlled by other means (3, 6).

The right amount and degree of cold is also important for the best blossoming of many trees and for improved quality of many deciduous and citrus fruits (1). Studies that are revealing the significance of night temperatures in the growth and quality of fruits (31) help explain the superiority of certain fruit-growing areas. Horticulturists have established the fact that deciduous fruit trees put forth a flush bloom only after a rather definite period of accumulated winter temperature at or below 45° F.; this is generally accepted as the temperature below which growth ceases and the trees rest. Investigations in the tung-growing sections of Florida indicate that tung trees also have optimum cold requirements (25).

SOME ORCHARD-HEATING EQUIPMENT USED OR AVAILABLE

Many types of burners and proposals for supplying heat for frost protection of orchards and truck crops have been tried during the past 40 years. A few are listed in table 2. Solid-fuel heaters, including wood heaters, the Frostlite, and the Frostpac, along with 11 oil-burning heaters, are included. The approximate number of heaters required per acre of the different types and their approximate costs are given, as are the fuel used and citations for further information.

The Frostpac was tested in Florida and abandoned. The Frostlite had been installed on small acreages in California as early as 1938, with additional new installations in 1947. This system is more expensive to operate than fuel-fired heaters (3). The oil-fired heaters, burning up to approximately 1 gallon per hour, range from the simple 5- and 10-quart lard-pail and 9-gallon sliding-cover types to the smokeless, return-stack heater, and to the Evans Frostguard, a large, smokeless unit producing a high output of radiant (infrared) energy and rated to burn about 10-1/2 gallons per hour.

Open flames from natural-gas-fired burners at the ends of long arms swinging around a central post were tried recently, but the writer has no further information. Although central plant-heating schemes have been advocated from time to time (30), they are considered impractical (1). More than 20 years ago, 31 different oil-burning heaters, which included most of the types then in use, were tested for smokiness in California. Only 5 of the heaters were found to be reasonably free from smoke at all usual burning rates under good operating conditions; 13 very smoky heaters were mostly of obsolete types (2).

Wood for orchard heating has been used principally in Florida. Oil is used more generally because experience has shown that, with the proper grade of oil, this fuel involves the least amount of labor (1). Coal-burning heaters were used in southern California for many years but have gone out of use entirely on account of the greater amount of labor required to fill, light, and refuel them and the non-uniform rate at which the heaters burn as a result of the irregular size and shape of the lumps of coal (1),Briquets, because of their uniform size and shape, are more desirable; briquets have advantages over oil in protecting small acreages in that the solid fuel is easily handled and stored and eliminates the need for storage and distribution tanks (1). For the same reasons, prepared anthracite is useful, as described below.

TABLE 2. - Summary of orchard-heating equipment

Name, description, or type of heater	Approx. number per acre[1]	Approx. cost, each, dollars	Fuel	References[2]
Frostguard (hot stack)..	1 to 10	350.00	**Kerosine and No. 1 fuel oil.**	See ref. 3, 9, 10, 14, 15, 16.
Frostpac................	130 to 350	Mfgr. discon.	3/4-gal. congealed petroleum.	See ref. 12.
Hy-Lo-230A, 24-inch stack (lazy flame)....	10 to 60	4.00	**Fuel oil.**	See ref. 1, 2, 5.[3]
Riverside junior louver 18-inch stack (lazy flame)................	10 to 60	3.50	do.	See ref. 5.
Fugit (generator-type)..	10 to 60	6.00	Light fuel oil.	See ref. 1, 2, 5.[4]
California salamander (hot stack)...........	10 to 60	Up to 9.00	**Kerosine and fuel oils.**	[4]
Jumbo cone (hot stack)..	10 to 60	5.00	**Fuel oil.**	See ref. 1, 2, 5.[3]
Exchange model, 7-inch stack (hot stack).....	10 to 60	-	do.	See ref. 2, 5.
Kittle (hot stack)......	10 to 60	-	do.	See ref. 1, 2, 5.
Return-stack (hot stack)	10 to 60	6.00	do.	See ref. 2, 5, 23, 27.[3]
9-gallon sliding cover..	60 to 70	1.50 to 1.75	do.	[5]
Lard pail...............	80 to 200	0.50 to 1.00	do.	See ref. 1, 8, 18.
Solid-fuel heaters......	60 to 125	0.70 (1925)	Coal briquets, carbon briquets, coal petroleum coke, coke from coal.	See ref. 1, 2, 5, 18.[6]
Wood heaters............	60 to 70	-	Wood.	See ref. 1, 18, 19.
Open wood fires.........	100 to 120	-	do.	See ref. 1, 18.
Frostlite (infrared lights)...............	4-1/2 to 25 kilowatt	750.00 to 1,500.00 per acre.	Electricity.	See ref. 1, 3.

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[1] Concentration of heaters depends on size of plot heated, border effect, wind, temperature, inversion, type of crop, rate of drop of air temperature, etc., and the numbers may be more or less than indicated above. There should be enough heaters to meet the most severe conditions, although they may occur not more than once a season. Only those necessary to meet the existing situation need be fired, but all will be in place in the area to be protected. Use of wind machine also influences number required. Large number needed if heater is type that will not burn through the night; refueling while heater is burning is impractical.

[2] Reference numbers in the last column refer to numbers in the bibliography at the end of this report.

[3] Information from Scheu Manufacturing Co., Upland, Calif.

[4] Information from California Heater Co., Pomona, Calif.

[5] Also letters from W. O. Johnson, June 4 and Aug. 12, 1952; Aug. 7, 1953; June 1, 1954.

[6] Also letters from W. A. Luce, Apr. 26, May 24, June 1, and June 15, 1954.

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The small salamander heater is generally used to fire solid fuels, and both top- and bottom-fired types have been used, depending upon the particular fuel employed. The Karr orchard heater was used extensively in the Pacific Northwest with briquets as fuel.[7] In the same area, there is some interest in developing a heater that could burn sawdust and other forms of waste wood; however, it is not known whether a successful heater of this type has been developed as yet.[8] It has been reported (2) that most of the solid-fuel heaters on the market were relatively small, with burning rates ranging from 2 to 5 pounds per hour, which is equivalent, in heat output, to only 2/10 to 1/2 gallon of fuel oil per hour, and is somewhat lower than the 1/2 to 3/4 gallon per hour normal burning rate of an oil heater; however, experimental heaters, using petroleum coke, were built large enough and operated in California during 1939-40 at burning rates comparable with oil-fired heaters; 5 pounds per hour was considered the minimum effective burning rate. The coke heater was studied because in 1939 petroleum coke had been made available in quantities adequate for orchard-heating needs at $4.50 per ton in bulk at the refinery, a price comparable with that paid for ordinary heater oil (2).

Results of the extensive studies in California of the characteristics and effectiveness of both oil-burning heaters and experimental solid-fuel (petroleum-coke-fired) heaters, at burning rates of about 3 to 9 pounds per hour, have demonstrated that the solid-fuel heater released a higher proportion of heat in the form of radiant energy than did any of the oil-fired heaters. As pointed out in the preceding chapter, this is a useful characteristic when areas must be heated during a period of high ceiling and weak inversion and is especially important in border areas so that the outside trees may be heated directly without the necessity for warming all of the inflowing air before it gets into the orchard (5).

Factors to be considered in selecting a frost-control heater and heater fuel include: Fuel availability and cost; method of lighting, controlling or adjusting, and extinguishing; labor in fueling and refueling; fuel storage; trouble-free operation; effective heating; and maintenance and heater costs.

A comparison of the relative labor requirements of solid-fuel heaters and lazy-flame oil heaters indicates that there is no substantial difference in the overall labor requirements (filling, lighting, refueling, regulating, extinguishing, and cleaning) for solid-fuel heaters and the lazy-flame oil heater, a common type. Solid-fuel heaters need no cleaning to maintain smokeless operation, whereas many of the so-called smokeless oil heaters must be cleaned regularly if good, smoke-free operation is to be maintained; moreover, efforts to eliminate soot and smoke altogether in oil heaters of the return-stack type lead to a more expensive unit, greater difficulty in lighting, and decrease in the range of possible burning rates (2). Comparative labor costs for several types of heaters in use are shown in table 3. Lighting the heaters is an important operating detail, and torches, using a gasoline and oil or kerosene mixture as fuel, are commonly used for this purpose. (1,2,19).

PENNSYLVANIA ANTHRACITE AS FUEL FOR FROST-CONTROL HEATERS

Pennsylvania anthracite is a naturally occurring, smokeless, solid fuel, mined and prepared for the market in northeastern Pennsylvania. It is available in a range of commercial sizes, of which the following two are probably most applicable to frost-control heaters:

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[7] Letters from W. A. Luce, Apr. 26, May 24, June 1, and June 15, 1954.
[8] Letter from A. S. Leonard, July 30, 1954.

TABLE 3. - Comparative costs in orchard heating[1]

Description of heated orchard	Equipment[2] investment per acre	Initial investment in fuel per acre	Average annual total cost of firing per acre	Fuel-cost portion of average annual total cost[3] of firing, percent	Labor-cost portion of average annual total cost of firing, percent	Cost of fuel per unit	
						Gallon	Tons
281 acres of lemons in southern California. Year: 1913. Equipped with small, open oil heaters; fired 19 times	-	-	$132.75	29.0	34.5	-	-
281 acres of lemons in southern California. Years: 1914-25, inclusive. Equipped with improved stack oil heaters; fired an average of 17 times per year	-	-	70.78	19.5	34.5	-	-
682 acres of lemons in southern California. Year: 1926. Equipped with improved stack oil heaters; fired 13 times	-	-	39.22	22.0	46.5	-	-
50 acres of oranges in southern California. Year: Before 1929. Equipped with double-stack heaters; fired 10 times	$168.00	$80.00	52.62	26.0	23.5	$0.040	-
40 acres of pears in the Rogue River Valley of Oregon. 5-year period before 1929. Equipped with lard-pail oil heaters; fired 5 times a year	55.00	27.00	23.60	43.0	21.0	.065	-
303 acres of apples and pears in the Yakima Valley, Wash. Years: 1925, 1926, 1927. Equipped with coal-briquet heaters; number of times fired per year unknown (probably between 5 and 10 times)	52.00	16.00	38.79	37.5	37.0	-	$12.00
42 acres of truck crops in Manatee County, Fla. Year: 1935. Equipped with open pot oil heaters; fired twice (10 hours total)	-	-	[4]23.97	-	-	.075	-
1 acre of strawberries in eastern Washington. Equipped with double-stack oil heaters; fired 3 times in April 1927 (heaters raised above ground)	-	-	158.20	[5]70.0	-	-	-
Same plot equipped slightly different heaters; fired once in the spring of 1928	-	-	91.97	-	-	-	-
1 acre of citrus in California. Equipped with Frostlite. Year: 1947	-	-	200.00	[6]21.0	-	-	-

[1] See references 1, 3, and 8. Except as noted elsewhere in footnotes to this table, only the percent fuel and labor costs are shown here. The balance to make up 100 percent of total cost consists of equipment costs, carrying charges and depreciation, maintenance costs, interest on stored fuel, taxes and insurance, and cost of lighter fuel.

[2] Includes heaters; storage, distribution and fuel ignition facilities; and thermometers.

[3] Fuel for igniting or lighting heater not included; lighting fuel is about 1 to 5 percent of heater fuel cost, depending mainly on number of firing periods per season and length of firing period.

[4] Does not include depreciation on equipment, interest on investment, or maintenance; includes only heater fuel, labor, and lighting fuel (1 to 2 percent of cost per acre given); heater fuel is 89 percent of the cost given.

[5] Percent operating cost is of total cost; no breakdown to fuel and labor costs.

[6] Percent minimum electric energy cost is of total cost, which includes depreciation, maintenance, interest, taxes and insurance, and electricity.

Stove size, through 2-7/16 inches, on 1-5/8-inch round-hole opening.
Chestnut size, through 1-5/8 inches, on 13/16-inch round-hole opening.

Under the Pennsylvania Anthracite Standards Law,[9] the size must fall within certain percentage limits for these openings and the ash content is limited to 11 percent on the dry basis. This fuel is available in the so-called hard- and free-burning varieties, which refers to their general combustibility characteristics. The hard-burning variety, containing less than approximately 4-1/2 percent volatile matter, is longer burning and slower to ignite than the free-burning variety, which contains more than about 6 percent volatile matter.

Anthracite has the numerous advantages of processed solid fuels for frost-control heating as follows: Investment cost for heaters is low. The smoke nuisance can be eliminated when desirable. The heat output has a high radiant-energy fraction, which is useful during periods of weak inversion and high ceiling. Anthracite is useful during periods of large and steady heat demand. Heaters do not have to be cleaned to maintain smokeless operation. There is no danger to root systems of trees from oil leakage from storage tanks or individual heaters. The fuel is easy to store and handle.

Experience with anthracite-fired salamander heaters used for various purposes essentially confirms the results of tests conducted in California (2) over 10 years ago with experimental solid-fuel heaters using petroleum coke and agrees with operating results described earlier for briquet heaters (1). In the characteristics of lighting and burning, control of length of burning period, fuel losses, storage and handling of fuel, labor requirements, and depreciation of heaters, the briquet-, coke-, and anthracite-fired heaters are similar.

Published information (6) is already available on the approximate heat requirements per acre per hour to raise air temperature 1° F. in frost-control work. (See earlier discussion under Factors in the Use of Heaters for Frost Protection.) In addition, records from actual practice (8, 15, 16) demonstrate fuel requirements per acre per hour to protect crops from frost damage when the temperature has reached a stated number of degrees Fahrenheit below freezing. (See subsequent discussion on economics and practices in Florida and Michigan.) It is only necessary, therefore, to determine the rate in pounds per hour at which Pennsylvania anthracite, of stated heating value and size, can be burned in an orchard or salamander heater typical of the kind that has been found practical in frost-control heating and to demonstrate typical burning and kindling characteristics of this fuel. To accomplish this, tests were conducted at Schuylkill Haven, Pa., with a 14-inch-diameter, bottom-fired salamander heater (fig. 1) equipped with a simple grate; this size heater was selected because it approximated the diameter of the coke heater taken as the minimum effective size in the work conducted, more than a decade ago in California (2). The results of these tests have demonstrated the burning characteristics of Pennsylvania anthracite that are pertinent to its use as fuel in frost-control heaters.

A Stove-size, free-burning anthracite (approximately 13,000 B.t.u. per pound) was fired at burning rates above 6 pounds per hour for nearly 3 hours with no further attention after lighting (fig. 2). Fuel charges, ranging from 40 to 60 pounds, were

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[9] Anthracite Standards Law: Reprints available from D. L. Corgan, secretary, Anthracite Committee, State Street Bldg., Harrisburg, Pa. Original act approved May 31, 1947; amended May 18, 1949, and Sept. 26, 1951.

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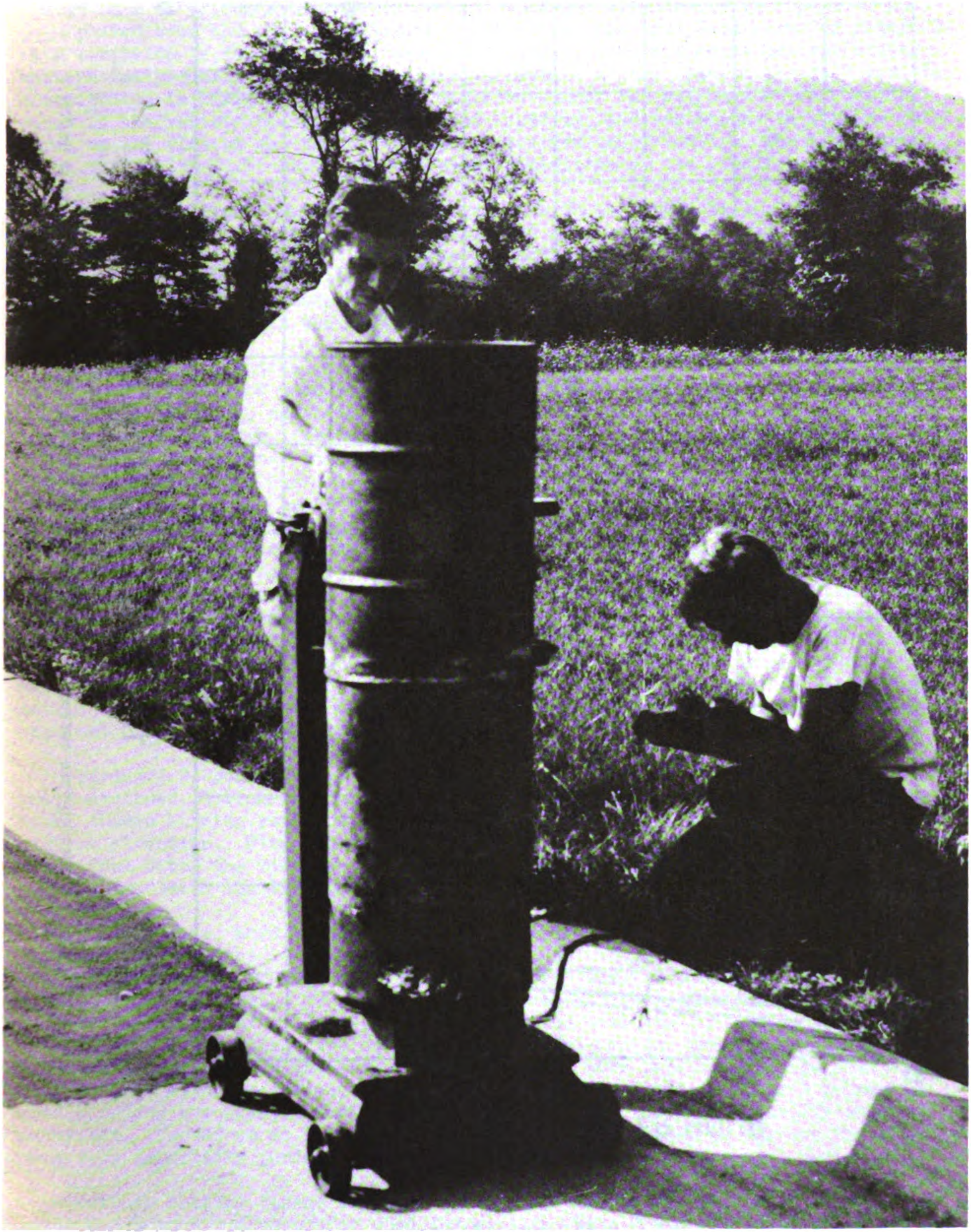

Figure 1. - Anthracite-fired salamander heater on scale during burning-rate tests.

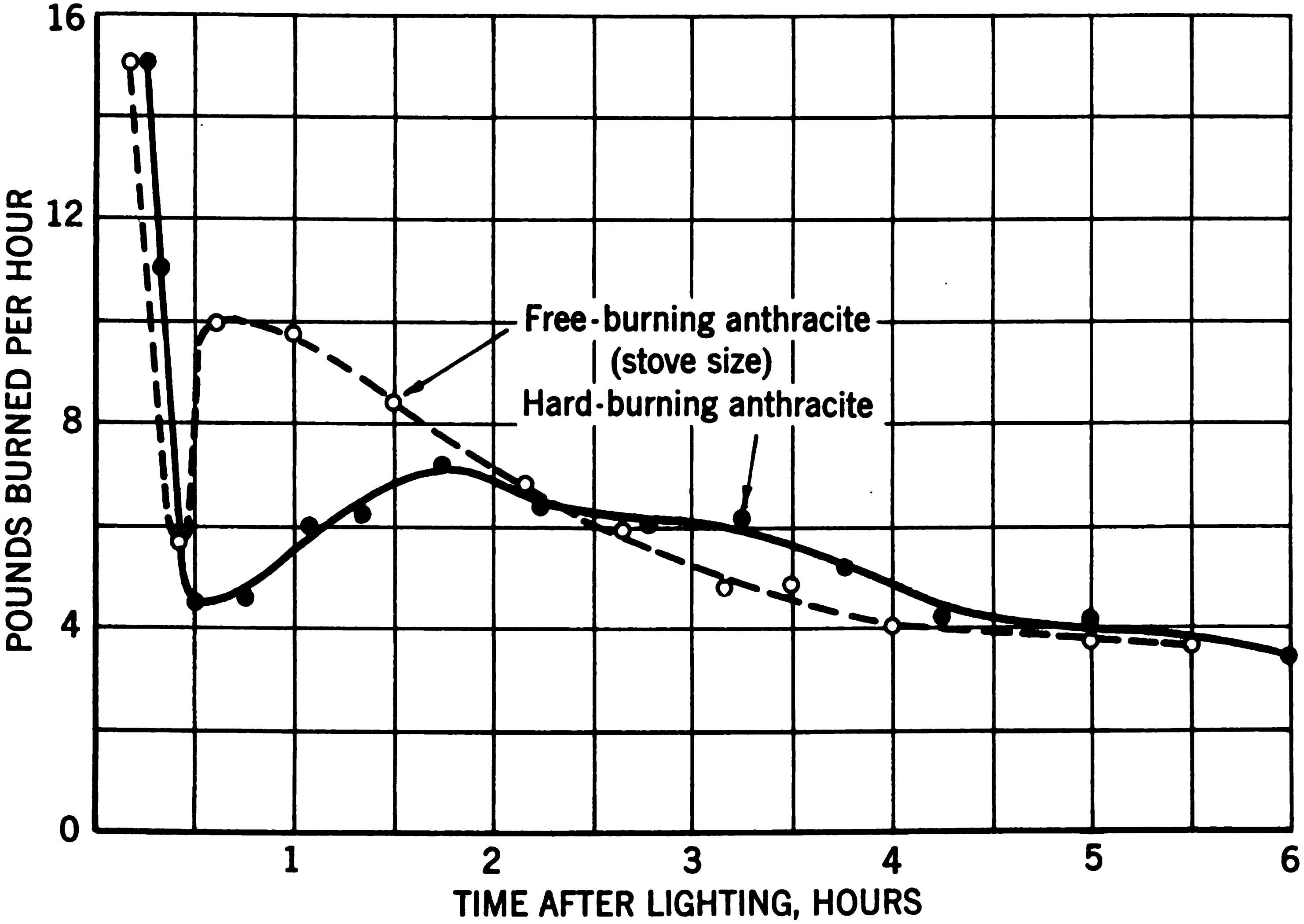

Figure 2. - Burning-rate curves for Pennsylvania anthracite fired in 14-inch-diameter heater.

placed on 2 to 3 pounds of kerosine-soaked wood for kindling, with 1 pint of kerosine poured over the fuel just before lighting the heater. Each curve in figure 2 is a composite of four separate tests; this typical curve smooths out variations between individual tests resulting from variations in the size of the fuel and its distribution in charging the heater, distribution of the oil on the fuel, differences in the variety and size of the wood kindling, and variations in weather conditions at the time of the tests, which were not run concurrently. The high burning rates during the first half hour represent combustion of the kindling materials.

This free-burning anthracite was ignited with as little as 1 pound of kindling and 1 pint of kerosine, but this was reflected in a more pronounced slowdown in the burning rate during the first hour after lighting and a longer time for the burning rate to reach a maximum. Using as much as 4-1/2 pounds of wood kindling with 1 pint of kerosine, the slowdown in burning rate could be substantially eliminated with no marked change in the burning-rate curve after the first hour (fig. 2).

Starting with initial charges of free-burning coal of about 30 to 45 pounds and using 2 to 3 pounds of wood kindling with 1 pint of kerosine poured over the fuel just before lighting, addition of 1 to 4 small increments of fuel at approximately 1-hour intervals after lighting, to give a total fuel charge of some 45 to 72 pounds, did not materially alter the burning-rate curve from that in figure 2, for approximately the same total fuel charge. In these tests, whether ashes were removed by careful shaking and poking or the fuel bed was undisturbed except for settling as the wood kindling burned, the characteristic burning-rate curve did not change after the first hour. In some tests, the slowdown in burning rate during the first hour was difficult to detect; however, with the smaller initial and total amounts of fuel, the rate did show a somewhat sharper fall-off within the first 3 hours, as might be expected. With the larger fuel charges, the leveling-off period was prolonged at a burning rate of about 4 pounds per hour; but, again, the rate dropped off slowly as the remaining fuel diminished below that required to supply the heat necessary to maintain the temperature and mass of active fuel bed corresponding to the 4-pound rate. With the largest total charge, the 4-pound-per-hour average burning rate was apparent 8-1/2 hours after lighting the heater.

Firing a 23-pound charge of the free-burning Stove anthracite in a simple, grate-equipped, bottom-fired salamander heater 11 inches in diameter by 26 inches high, showed burning rates of 2 to 3 pounds per hour could be sustained for 3 hours without attention. With the smaller heater, however, the fuel losses from unconsumed fuel after the fire had burned out were several-fold greater than the 3 to 5 percent lost with the 14-inch-diameter heater for a single firing.

A Stove-size, hard-burning anthracite (approximately 13,000 B.t.u. per pound) was also fired in the 14-inch-diameter heater, but the burning rates were lower (fig. 2) than with the free-burning variety under similar conditions. Fuel charges, ranging from about 30 to 52 pounds, were placed on 3 to 4 pounds of kerosine-soaked wood for kindling, with 1 pint of kerosine poured over the fuel just before lighting the heater. The burning-rate curve in figure 2 is typical for the hard-burning anthracite used, except that the rate dropped off more rapidly with the smaller charges than with the larger charges. When less than about 2-1/2 to 3 pounds of wood kindling was used, ignition of this hard-burning fuel was generally slow and uncertain. Use of up to 6 pounds of kindling did not appear to improve the burning rate very materially during the first hour over the rate with 3 to 4 pounds.

With an initial charge of about 25 to 40 pounds of the hard-burning coal and using 2-3/4 to 3-3/4 pounds of wood for kindling with 1 pint of kerosine poured over the fuel just before lighting, adding 2 to 3 increments of fuel within 2 hours after lighting to give a total charge of some 50 to 75 pounds, with no other disturbance of the fuel bed did not appear to alter the burning-rate curve significantly from that in figure 2 for corresponding total fuel charges. With larger charges, the same addition only lengthened the period during which burning held at the 4-pound rate.

The firing of Nut-size, hard-burning anthracite in the test heater showed no appreciable difference in characteristic burning rate or kindling behavior over that with the Stove size (fig. 2). There was no indication of any increased burning rate of practical significance in the test heater, as might be expected for this somewhat smaller sized fuel.

While firing the 14-inch-diameter heater, ashes of approximately 28-pound-per-cubic-foot bulk density were built up on the grate at an average apparent rate of about 1 inch of ashes for each 10 pounds of fuel charged, both for the free- and hard-burning varieties.

Tests with a top-fired salamander, 11 inches in diameter by 26 inches high, in which the combustion air enters through the open top of the heater and holes in the cylindrical heater wall, indicated the doubtful suitability of anthracite as fuel in the top-fired type of orchard heater. Although both the free- and hard-burning anthracites could be kindled in the top-fired heater, neither would produce a self-sustaining fire that lasted more than a short time. The free-burning anthracite could be ignited simply by placing 2-1/4 pounds of kerosine-soaked wood kindling on top of the fuel charge in the heater with 1 pint of a 50-50 lighting mixture of gasoline and oil poured over the fuel just before ignition. This procedure was ineffective with the hard-burning variety, which was satisfactorily ignited by placing 4 pounds of kerosine-soaked kindling on top of the fuel charge, placing 8 to 10 pounds of the anthracite on the kindling, and pouring another pint of the above lighting mixture over the fuel just before touching fire to the heater.

Summarizing, it has been found that, with no further attention after lighting, both free- and hard-burning Pennsylvania anthracites can be burned in a 14-inch-diameter, bottom-fired salamander heater at rates of 4 pounds per hour, and above, for upwards of 3 to more than 8 hours, depending on the total amount of fuel charged to the heater.

In conclusion, an approximation of unit equivalent fuel costs at point of use for frost-control heating under a given set of conditions is useful here because it allows an insight into the general picture of competitive fuels in this application and reveals some of the limiting factors and prospects for growth of this practice in the face of rising costs of operation.

If it is assumed that a fuel consumption of 3-1/2 million B.t.u. per acre per hour is enough to protect a 25-acre plot from frost damage when the lowest temperature is 28° F., then equivalent fuel costs for the fuels indicated below are as follows:

Heater fuel cost per acre per hour	Anthracite (13,000 B.t.u. per pound), per net ton	Heater oil (140,000 B.t.u. per gallon), per gallon
$1.25	$9.30	$0.050
1.88	13.95	.075
2.50	18.60	.100
3.13	23.25	.125
3.75	27.90	.150

Thus, if 13,000 B.t.u. per pound anthracite suitable for heater fuel were available at the point of use for $18.60 per ton, all other things equal, it should be comparable in value to oil at 10 cents per gallon to give a heater fuel cost of $2.50 per acre per hour for a moderate heat requirement, which on very small plots may be several-fold higher.

ECONOMICS AND EXTENT OF FROST-PROTECTION PRACTICES

No general statements can be made as to the advisability of installing heating equipment for frost protection except to state that: (1) Quantity and quality production of the crop must always be considered; (2) heating will protect from frost but will not protect from a general cold wave or freeze; (3) plantings so located that they are exposed frequently to temperatures so low that an increase of 5° to 8° F. will not protect them from injury present a problem that heating will not solve; and (4) the grower who has to heat a considerable acreage to get a crop is at a distinct disadvantage in competing with the grower who does not have this added expense, because it is for the occasional grower rather than the general run that heating will be profitable (1, 6, 13, 41).

Whether heating will pay at a given location depends, largely, upon the amount and quality of the crop produced, because the cost of heating goes by the acre whether the yield is large or small or the quality good or inferior, and the net income for heating comes only from the crop saved. But, net income is not the only consideration in determining whether heating or other frost-protection practices will pay because, when a crop is destroyed by frost, the loss includes not only the net profit on the crop but, also, the season's expense of caring for the planting, interest on investment, and other expense (1).

In the subsequent discussion the prospects for frost-control heating, in general, and the use of anthracite as heater fuel, in particular, are outlined. This is based on a description and examination of cultural practices and of the magnitude, value, and distribution of orchard, small-fruit, and truck crops in widely separated states and in several states within or near the usual anthracite-marketing area. Insofar as information was obtainable, a description of the variations in practices and needs and in the degree and extent to which frost-protective measures have been or are being employed forms an integral part of the discussion and of the appraisal.

In drawing on the United States Census of Agriculture figures (42), which are cited frequently in the sections following, the expressions "total citrus acreage," "tree fruits of all ages," and "vegetables (or other crop) harvested for sale" are used. The first two refer to the acreage of citrus or other fruits of both bearing and nonbearing age, and the last is used to distinguish this acreage from that on which vegetables are grown for home use. The census figures include no details of acreage, variety, or value of vegetables grown for home use, and simply list the number of farms reporting.

California

Orchards have been heated in California for many years. In 1952 it was reported (6) that 4 million heaters are still in citrus orchards, but antismoke ordinances require elimination of smoky types. One of the largest lemon groves in southern California began heating as early as 1912, and costs for 1913-26 with oil-fired heaters are shown in table 3. The average total cost of heating at this orchard was approximately $73 per acre per year for 1913-26, during which the heaters were fired an average of 17 times per year. Fuel costs made up about 21 percent of the total, labor amounted to 35 percent, and depreciation, interest, and upkeep the remaining 44 percent. At this orchard, frost-protection costs are for the probable maximum number of firings per season that might be necessary anywhere in the country (1).

Although heating costs are now about twice as great as they were before 1940, it is believed that, in California, frost-protection efforts by citrus growers are worth, today, an average expenditure of over 1 million dollars per year, which is about 1 percent of the nearly $128 million value of the total citrus crop in 1952. 10/ However, with the greatly increased heating costs and no appreciable rise in fruit price as a consequence of a freeze, the statement has been made that some growers who profited by frost protection 30 years ago cannot now afford to use installed equipment, even though its capital cost was written off long ago. Although no close average can be stated, the general opinion, at least in California, is that the grower who has to heat more than 6 or 7 nights per year is probably losing money on the operation (6).

With rising costs for frost protection with heaters, wind machines, despite their limitations, have found increased acceptance by growers because of low operating cost. A recent type of wind machine or Frostguard installation is shown in figure 3 (35). Careful field studies for Los Angeles County, reported in 1950 (24), show heating to cost about $3.60 per acre-hour; wind machines $0.55; a combination of the two about $0.67 per acre-hour, with the wind machines running about 100 hours per season. Thus, to heat a crop, a single 5-hour firing period would cost $18 per acre. Compare this with costs before 1930 of $3 to $7 per acre per firing for mass heating lemon and orange groves, as listed in table 3. In contrast, 3 firings in April 1927, on approximately 1 acre of strawberries in Washington, showed a cost of about $53 per acre per firing.

Acceptance of wind machines, which came into use over 30 years ago, was slow, but it was pointed out in 1952 (6) that the combination of wind machines and heaters (8 to 15 heaters per acre with wind machines instead of 25 to 50 without wind machines) meets the usual radiation frost conditions in California so well it is now the accepted system for economical protection at an approximate investment cost of about $400 per acre for the combination. The extent of acceptance of this system (6) can be seen in the more than 2,800 wind machines installed in 1952, of which 2,000 are of 70 horsepower or more, with all types representing an investment of over 8 million dollars.

The total B.t.u. consumption in heating California citrus groves, using improved stack and double-stack oil heaters only, amounted to about 2-1/3 to 4-3/4 million B.t.u. per acre per firing for 10 to 17 firings per season on plots as small as 50 acres and as large as nearly 700 acres, when calculated from the estimated heat content of the oil consumed. Using small, open oil heaters, the total B.t.u. consumption amounted to a little more than 7 million B.t.u. per acre per firing for 19 firings in a season on a plot of more than 275 acres.

Solid-fuel-fired heaters have been used, to a limited extent, in the citrus districts of California. The fuels have included petroleum coke, coke briquets, carbon birquets, and coal briquets;however, up to 1940, the acreage equipped with

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10/ Based on information from the California Crop and Livestock Reporting Service, Department of Agriculture, Sacramento, Calif.

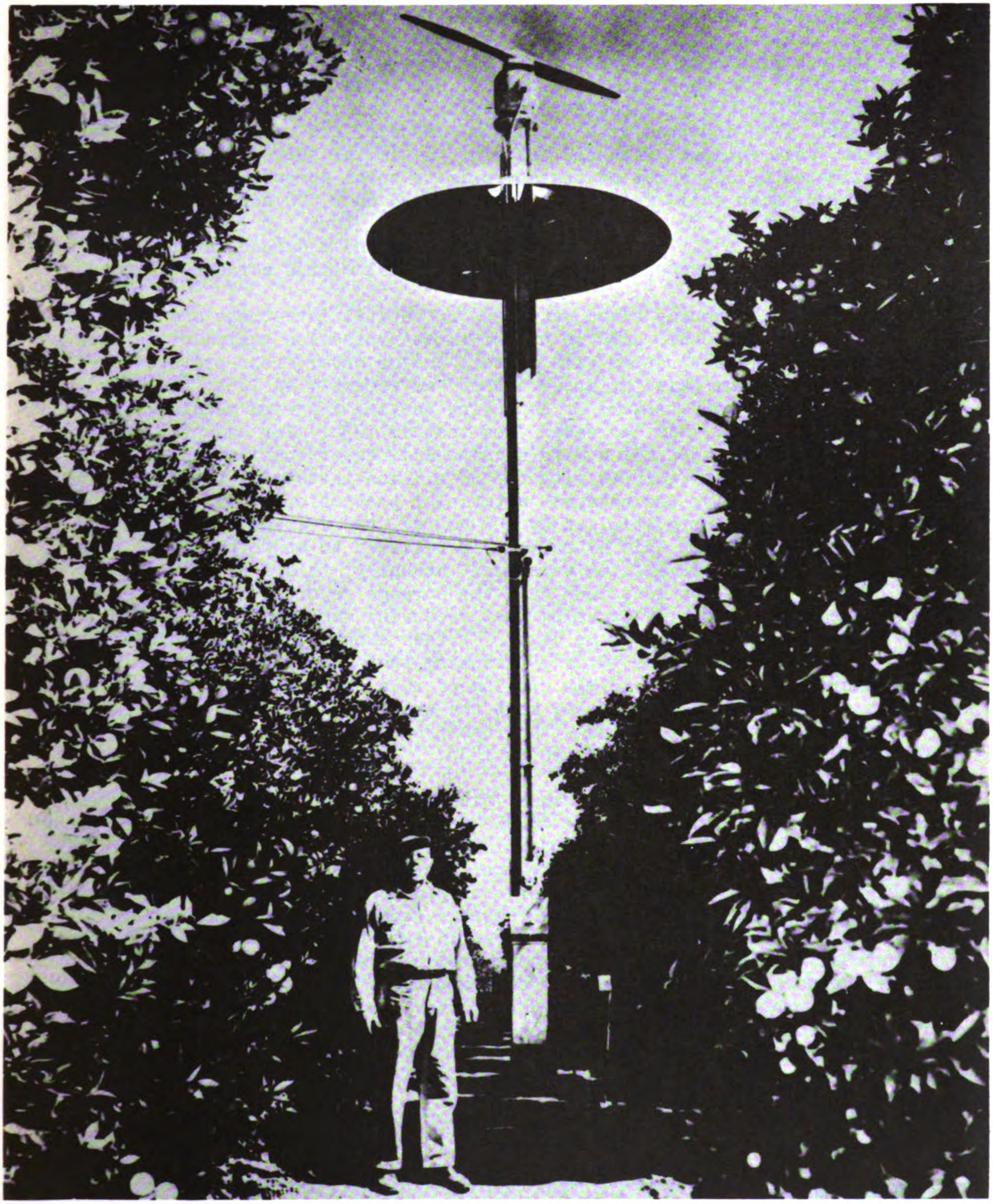

Figure 3. - Automatic "Frostguard" or wind machine installed in citrus grove. (A 25-horsepower motor, turning the 6-foot propellor, is actuated by means of the air thermostat mounted on the pole within the tree zone.)

solid-fuel heaters appears to have gone only a little above 10 percent of the heater-equipped acreage (1, 2). This is believed attributable, largely, to the unavailability and high cost of these fuels compared with oil (2). As a result of a survey in 1928 (1), it was found that some 52,000 acres of the total citrus acreage of approximately 214,000 were heater equipped. Of this total, about 3,700 acres, or 1.7 percent, were equipped with solid-fuel heaters, and about 48,300 acres, or 22.5 percent, were equipped with oil heaters. A similar survey in 1938 (1) revealed that an estimated 92,000 acres of the approximate total acreage of 317,500 were heater equipped, with solid-fuel heaters being used on 9,500 acres or 3 percent, whereas 82,500 acres or 26 percent used oil heaters. Thus, in 1928, the heater-equipped acreage was a little more than 24 percent, and a decade later, in 1938, it had increased to an estimated 29 percent of the total citrus acreage surveyed.

By comparing previously cited estimates of capital investment and annual expenditures, along with other data on use of frost-protection equipment, a more recent estimate of the acreage equipped with heaters and/or other frost-protection equipment is possible. From this, it appears that, as recently as 1952, the citrus acreage, either equipped with heaters or employing heating and wind machines, has shown no increase and probably has decreased from that in 1938. For example, at an investment of $400 per acre for a wind-machine-and-heater combination, about 20,000 acres could have been so equipped with the $8 million investment noted previously. Using wind machines only, the cheapest artificial protection at $55 per acre annually ($0.55 per acre-hour multiplied by 100 hours), the average expenditure of over $1 million annually, which this extra help is believed to be worth, would cover about 20,000 acres. If $2 million were spent annually, this acreage would be doubled but would still be less than half the acreage reported above as being equipped with heaters in 1938. By assuming that each wind machine can effectively cover 10 to 15 acres (which appears to be high (6)),then about 3,000 wind machines will cover 30 to 45 thousand acres. Only by assuming that there are 4 million heaters in citrus orchards (as mentioned in the opening of this chapter), that these are placed 50 heaters to the acre, and that they meet the antismoke-ordinance requirements, does the acreage (80,000) equipped with frost-protection equipment approach the figure of 92,000 heater-equipped acres in 1938.

Summarizing, it is to be noted that, although the 1952 total citrus acreage was 280,000,[11] which is down nearly 40,000 acres from the 1938 level, the acreage equipped with and employing frost-protection equipment in 1952 probably maintained neither the protected acreage nor the proportion of protected acreage cited earlier for 1938. In 1938 the solid-fuel-heater-equipped acreage constituted slightly over 10 percent of the total heater-equipped acreage, compared with 7 percent in 1928; however, there is no evidence that use of solid-fuel heaters has increased since 1938; instead, current reports[12 13] range from partial to complete abandonment of solid-fuel heaters because of the lack of a source of cheap solid fuel. Thus, conversion of any present acreage equipped for other fuels to the use of solid fuels would, if possible or likely, require a new investment in solid-fuel heaters. Furthermore, it has been suggested[14] that as long as oil is available, and not too expensive, a return to the use of any type of solid fuel for frost protection is very doubtful.

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[11] See footnote 10.
[12] Letter from F. D. Young, June 14, 1954.
[13] Letter from A. S. Leonard, July 30, 1954.
[14] See footnote 12.

Florida

For many years, growers used wood fires for frost protection in this State. A native type of fat pine was readily available at a reasonable price and could be stacked in the open with very little deterioration. In recent years, the supply has diminished, and, with increased labor cost, the use of fat pine has been largely discontinued, except where growers have a supply on hand (19).[15]

The current situation in citrus-grove heating is Florida is similar to that in California; however, a 1954 report (47) claims that citrus "production costs in California are easily double those of Florida," because of higher labor costs, land values, heating costs, and other operating costs. Although the total citrus acreage was approximately 468 thousand acres in the 1952-53 season, it is reported that, at present, there is a noticeable decrease in citrus-grove heating because of the low return on the fruit, which, in the 1952-53 season, had a total value of about $124-1/2 million. Furthermore, the percentage of citrus acreage heated in Florida is very small and, since critically cold weather is infrequent, the number of firings each season is not very great because the vast bulk of citrus acreage is concentrated across the central part of the State. On the other hand, protection of truck crops from frost damage has become increasingly important in this State, where the truck-crop acreage was over 309,000 in the 1951-52 season and the value was nearly $159 million.[16]

A few truck farmers are reported to use oil-burning heaters, but the margin of profit is so small that the majority find it "almost uneconomical to add heating cost and still receive a profit." A large number of growers of truck crops irrigate heavily when low temperatures are forecast, which affords a small degree of protection, covering is used by others, and some do nothing. It is believed that a more economical method of protecting truck crops would benefit the vegetable industry of Florida considerably.[17]

The importance of frost protection to truck farmers is brought out in a report (8), which describes experience and costs in heating 42 acres of nearly mature tomatoes, peppers, eggplants, and Irish potatoes on 2 nights late in December 1935, near Oneco in Manatee County. Unprotected truck on the same farm was severely damaged. Fuel and labor costs for heating averaged $2.40 per acre-hour for the 2 firings (see table 3), which totaled 10 hours. A total of 12,000 gallons of fuel oil and 105 gallons of lighting mixture were consumed during the 2 firings. Using 4-quart and 15-quart open oil pots, 4 million B.t.u. per acre per hour, based on the estimated heat content of the oil consumed, was enough to protect the given plot when the temperature fell to 29° F., and wind reached as high as 20 miles per hour during 1 firing period. The operating cost for protecting the given acreage amounted to about $1,007, or approximately $100 per hour of firing. Fuel cost made up nearly 90 percent of this expenditure. The crop, which by 1936 prices was valued at approximately $40,000, would have been lost without heating. The cost of these 2 firings was 2-1/2 percent of the estimated value of the crop; thus, a limit certainly does exist in the number of firings that a grower can justify in frost control.

In a single night's test near Zellwood in late November 1950, 4 Frostguard heaters protected 4/10-acre of tender string beans from frost damage threatened by

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[15] Letters from W. O. Johnson, June 14 and Aug. 12, 1952; Aug. 7, 1953; June 1, 1954.

[16] See footnote 15.

[17] See footnote 15.

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heavy frost and low temperatures, the lowest being 27° F. From the test results (10), it is estimated that the firing lasted about 8-3/4 hours, during which each heater consumed approximately 13-1/2 gallons of fuel per hour for an estimated operating cost (fuel and labor only) of some $27 per acre-hour for 1 night's protection, which is rather high as costs go for small plots. To afford protection in this test, when the temperature reached 27° F. the oil consumption was equivalent to about 19 million B.t.u. per acre per hour. All parties participating in the test agreed that the cost of equipment to protect tender crops under these conditions appeared to be prohibitive.

Economical practices in protecting fern from frost damage are also important because (1) nearly 3,000 acres of this valuable crop, worth up to $2,500 per acre per year, are grown in several counties, with half the acreage being in Volusia County; (2) fern is highly susceptible to cold and frost; and (3) growers must maintain a constant supply to meet market demands and to hold florist customers. It is believed that protecting fern by heating is a paying proposition today, provided the best practices in frost protection are observed in order to keep the number of nights of firing to a minimum. This involves use of good thermometers, which are exposed properly, maintaining a close watch on cold nights, and firing only enough heaters to maintain the temperature under the slat roof of the fernery at about 28° F., or to keep frost from forming (11).

The 9-gallon, sliding-cover oil heater (fig. 4) has been recommended as the most practical in Florida, although the Jumbo heater (see table 2), which costs more and requires more storage space, is more efficient.18/

In examining the possibilities for anthracite-fired, solid-fuel heaters in Florida, it has been pointed out that ease of firing must be given consideration since, in any type of heater, it is essential that the fuel used ignites easily and quickly and continues burning with little, if any, additional attention. The uncertain availability of labor for night firing makes it desirable that heaters use fuel that requires a minimum of attention. Only if fuel economy offsets added labor costs and if its other properties, such as ease of storing, refueling, and lighting, are comparable with those of other fuels, would a solid fuel be acceptable.19/

Although no statistics were obtainable on the proportion of citrus and truck-crop acreage subjected to heating and other frost-protection practices in this State, the available evidence presented in the preceding and succeeding paragraphs points toward no more than a very small percentage being heated each year, on the average.

On the basis of the data (6) cited previously, it may be estimated that California citrus growers can afford an annual expenditure for frost-control measures that amounts to about 3/4 to 1-1/2 percent of the value of the 1952 citrus crop, which was worth approximately $456 per acre of total citrus (280 thousand acres). Thus, an average of $3.43 to $6.85 per acre per year can be spent to protect California citrus, which would provide about 1 to 2 hours of heating per season at today's prices. Or, to have as little as 10 hours of heating per acre per season, it is apparent that only about 10 percent of the acreage can be heated for the indicated expenditure.

If it is assumed that the above percentage expenditure for frost protection can also be carried by Florida citrus, where the 1952-53 crop had a value of about $266

18/ Letters from W. O. Johnson, June 4 and Aug. 12, 1952; Aug. 7, 1953; and June 1, 1954.

19/ See footnote 18.

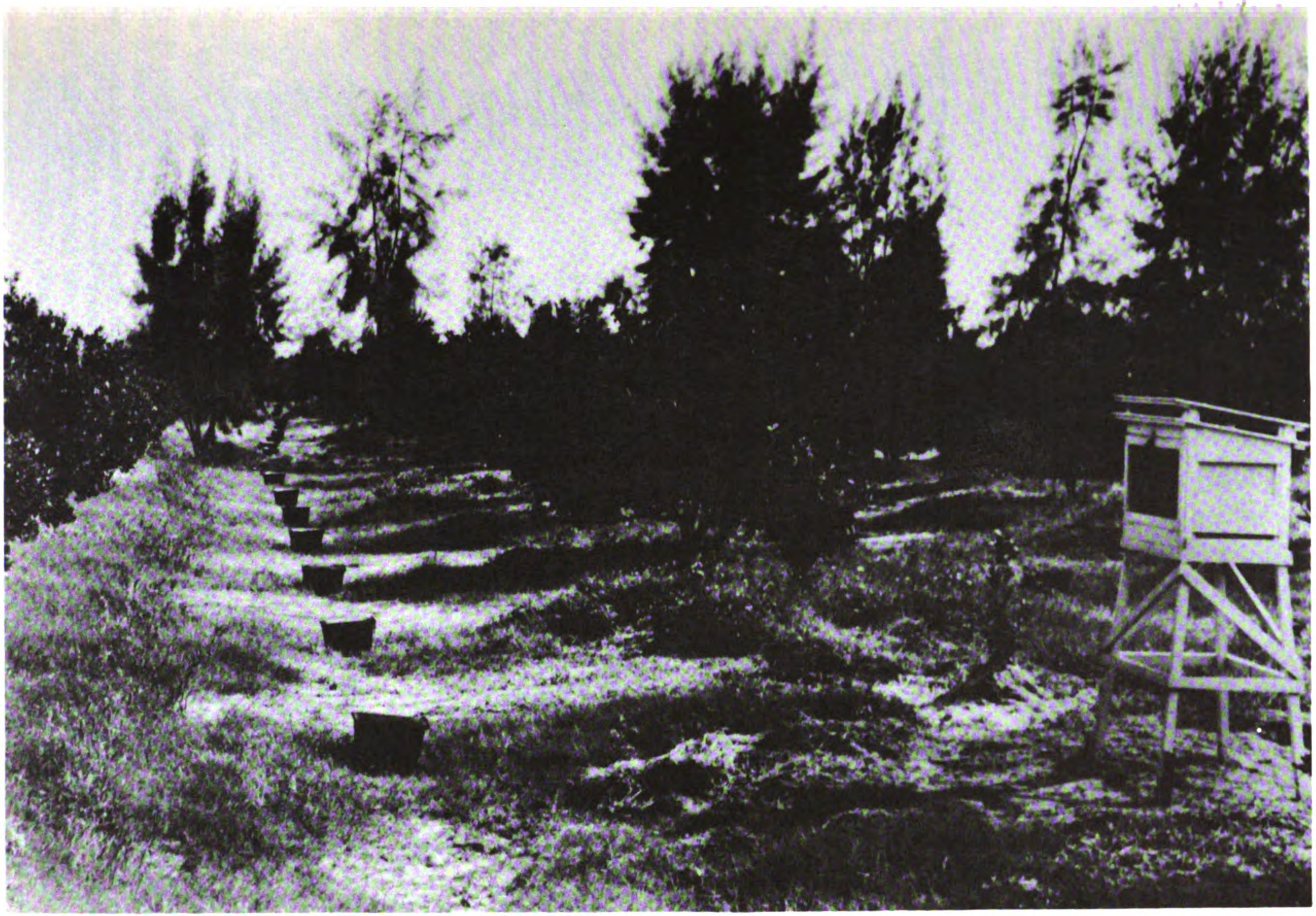

Figure 4. - Nine-gallon, sliding-cover oil heaters in Florida grove.

per acre of total citrus (468 thousand acres), then an average of about $2 to $4 per acre per year, or about one-half the estimated average for California, could be spent to protect citrus in Florida. At current costs, this would buy, perhaps, 3/4 to 1-1/2 hours of heating per season; consequently, the proportion of the acreage that can be heated as much as 10 hours in a season is very small, perhaps 5 percent. In view of the average low returns per acre on citrus, this estimated expenditure for frost control is, no doubt, higher than can be carried today. It is to be noted, also, that the value of truck crops in Florida amounted to about $514 per acre in the 1951-52 season, nearly twice the value of the citrus per acre the following season; yet, as pointed out earlier in this section, few growers find it profitable to add heating costs to their other costs, with the result that a more economical method of frost protection is desirable.

Pacific Northwest

Deciduous orchards and low-growing crops have been heated to protect them from frost damage for more than a quarter century in Washington and Oregon. Table 3 lists some heating costs of 25 years ago, which can be adjusted to give approximate present-day costs for the same operations. Today, labor costs are about two times greater, and fuel costs about one-third to two times greater, than those used in table 3.

Over a 5-year period before 1929, the average annual total cost of heating a 40-acre pear orchard located in the Rogue River Valley of Oregon, using lard-pail oil heaters, was $23.60 per acre, including fuel. labor, interest, and depreciation; the fuel made up about $10 of this cost (1). Some 4-1/3 million B.t.u. per acre per firing, or about 21-3/4 B.t.u. per acre per year, based on the estimated heat content of the oil consumed, were sufficient to protect this orchard.

From 1925 through 1927, the average annual total cost of heating 303 acres of apples and pears in the Yakima Valley of Washington, using coal-briquet heaters (18,000 at 68 cents each), ranged from $27.89 to $49.33 per acre, including fuel, labor, maintenance, interest (including interest on stored fuel), and depreciation; the fuel made up from $6.35 to $13.60 of these costs (1) (see table 3). About 31-1/2 million B.t.u. per acre per year, assuming fuel of 13,000 B.t.u. per pound, were required to protect this larger acreage from frost damage in an area where frost posed a somewhat greater problem than in other areas of Washington, as noted below. At 3-1/2 million B.t.u. per acre per hour, this would be equivalent to 9 hours of firing per year.

The cost of heating single acres or small plots shows up in costs reported for a 1-acre plot of strawberries in eastern Washington (table 3) when temperatures were below freezing for 9 consecutive hours on 1 of the 3 nights of firing. The cost per acre is greater than for mass heating of larger plots wherein the influence of border effect on heat requirements is much smaller. Cranberries have also been protected satisfactorily in plots as small as one-half acre in western Washington by firing lard-pail oil heaters placed on iron tripods to avoid burning the vines (1).

Current experiences of growers in Washington indicate that, in addition to the conditions noted previously, heating is justified where frost occurs frequently (frost pockets), but not in relatively warmer areas, and where the frost damage and marking loss amounts to as much as one-quarter of the crop every second or third year (41). Frost poses somewhat of a greater problem in the Yakima area than in the Wenatchee area, where many simple pot-type and single-stack, California-type, oil-burning heaters are in use.20/

20/ Letter from A. Van Doren, Apr. 2, 1954.

Solid fuels of various kinds have been used in the fruit-growing areas of the Pacific Northwest for many years, with considerable experience being gained in their use.[21] Briquets were used quite extensively in the Karr briquet heater (fig. 5), which is very efficient and effective, but slow to start, and impossible to put out when temperatures go above the critical point.[22] At present, the most common fuel is oil[23] because it has proved to be the most convenient, sure, and economical (41). As a result, the use of solid fuel for orchard heating has just about passed out of the picture in this area.[24]

Orchard heating has been on the increase in the fruit districts of Washington since 1940, when 2 percent of the total acreage was heated. By 1950, when the total acreage in fruits in the Washington fruit districts was 97,415 with a crop value estimated to be approximately $92 million, or about $945 per acre, the heated acreage had increased to 5 percent of the total. In 1952 the heated acreage was 10 percent and in 1954, 15 percent of the total acreage. In round numbers, the heated acreage has increased from about 2,000 acres in 1940 to 15,000 in 1954. This increase is attributable to a number of factors including: (1) Growers turning to more profitable varieties of fruits such as Red Delicious apples, which are especially tender to spring frosts, sweet cherries, which are sensitive to low temperatures during the prebloom stage in early April, and Bartlett pears planted generally on lower ground, which is more subject to spring frosts; and (2) a cycle of cold weather in which winter freezes or spring frosts, or both, have damaged crops each year since 1950, with the result that once a grower loses a few crops he invests in orchard heaters for self-protection.[25]

Michigan

In this State, effective and economical means of protection from frost damage have been intensely investigated in the past decade, including the use of heaters (14, 15, 16), stirring the air with helicopters (17), and sprinkling or irrigation (40). Interest was intensified from 1948-50 because there were numerous and damaging frosts during the strawberry-blooming period in southwestern Michigan where some 10,000 acres of strawberries are grown, but in the 3 years following there was no serious spring frost. Again, in early May 1954, a series of freezing temperatures were experienced in southwestern Michigan with an average loss in unprotected fields probably exceeding 50 percent of the strawberry blossoms (40).

As part of this program, the Frostguard, a large, infrared, radiant-type, oil-burning heater, rated at about 1-1/4 million B.t.u. per hour output, was developed and turned over to industry for manufacture (3, 14, 15, 16). The unit was reportedly designed to handle 1 acre, probably because the normal radiation heat loss per acre is about 1 million B.t.u. per hour; however, it was pointed out by those who developed the unit that the area that can be protected effectively by 1 unit will vary considerably, depending upon the crop, its stage of development and consequent critical temperature, and upon local topography, soil cover, atmospheric temperature and humidity, degree of wind, and extent of sky cover (14). Tests conducted in the fall of 1948 showed that tomatoes were protected effectively at 26° F., using 1 heater per half acre; at around 29° F., each machine protected about 0.7 acre. The machines were operated for periods as long as 12-1/2 hours and consumed an average of 10.8 gallons of kerosine per hour, or about 2-1/5 to 3 million B.t.u. per acre

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[21] Letter from W. J. Rogers, Mar. 30, 1954.
[22] Letters from W. A. Luce, Apr. 26, May 24, June 1, and June 15, 1954.
[23] See footnote 21.
[24] See footnote 22.
[25] See footnote 23.

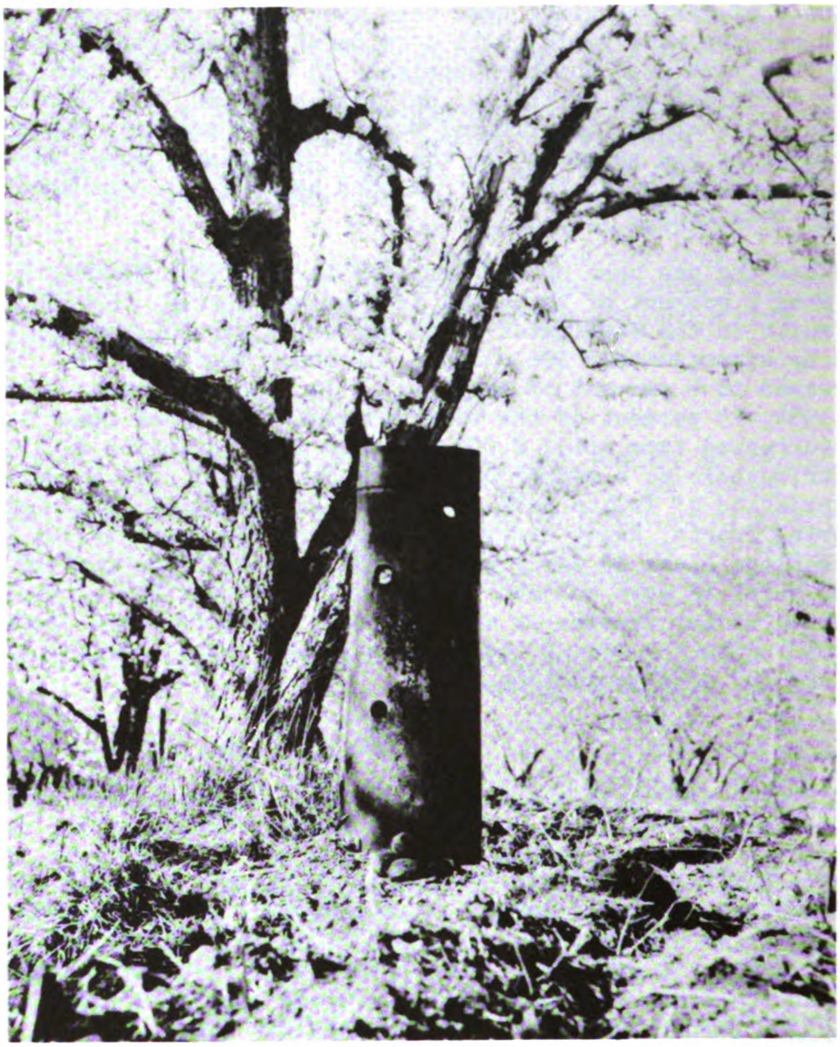

Figure 5. - Karr briquet heater in deciduous orchard in Pacific Northwest.

per hour for fuel of 140,000 B.t.u. per gallon. It was estimated that the growing season for tomatoes in the protected area, in the vicinity of Lansing, was lengthened by 13 days. The growing season in this area was terminated on October 18 by a windborne freeze, which was preceded by a cool wind of 8 miles per hour and over, that carried away more heat from the stems of the tomato plants than could be replaced by the heaters (15).

In the spring of 1949, frost-protection tests were conducted on strawberries. Four Frostguard heaters were installed in a field, and it was found that 1 heater afforded good protection to strawberries within a 50-foot radius (about 0.2 acre) when the temperature was 21° F., and there was some protection much farther. Because the operator in this test had not taken accurate temperature readings in the field at the crop level, the heaters were not fired properly on a few nights. Yet, for all practical purposes, 1 night's firing of 4-3/4 hours on May 11, during which each of the 4 heaters consumed "somewhat less than 10 gallons of fuel per hour," supplied enough protection to produce a yield difference of 71.74 additional crates of strawberries per acre in favor of the protected plot compared with the unprotected plot. After deducting the handling costs, the additional fruit brought in a gross income of about $232 more per acre from the protected plot than from the unprotected plot (16). This additional income per acre may be more apparent than real if the fuel cost per acre heated and the annual cost of the heaters are taken into account.

Because frost protection, using the infrared, frost-protection heater, was deemed too expensive, concurrent tests by growers in 1948 revealed that sprinkler irrigation could afford protection from frost, and, during the 4 severe spring frosts of 1949, irrigation was found to be an effective means of preventing frost damage to strawberries when temperatures went to 23° F. on the final night. Information obtained in 1948 and during the first three frosts of 1949 was passed on to all growers by radio. By the time of the final and most severe frost in 1949, nearly every strawberry-irrigation system in southwestern Michigan was operating (40).

The experience gained by growers during this cold period of 1948-50 was summed up in several conclusions: (1) Use small-capacity sprinklers and cover all areas of the field; (2) well or lake water may be used, as its temperature has little or no effect on frost prevention; (3) begin irrigating when the falling temperature reaches 34° F., and continue sprinkling until the rising temperature has gone above 32° F. (continued sprinkling until all ice on plants has melted is recommended by some observers); (4) use a frost alarm to awaken the grower when the outside temperature reaches the danger point; (5) predetermine the temperature difference between the location of the frost alarm and the lowest point in the strawberry bed; (6) set up and test the irrigation system before the frost occurs (40).

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Because there were no spring frosts between 1950 and 1954, further experience with irrigation as a means of preventing frost damage was limited to experiments (40) to protect tender peppers, tomatoes, squash, and sweet corn during heavy frost in autumn; it was found that as little as 0.15 inch of water per hour, or approximately 4,100 gallons per acre per hour, was enough to prevent frost damage. On this basis, the cost of water for protecting strawberries from frost damage by sprinkling from the irrigation system would be about $1 per acre per hour, with water costing 25 cents per 1,000 gallons.

A current estimate[26] of the extent of frost-protective measures employed in this State shows that 10 percent of the vegetable acreage is protected by irrigation and 20 percent by Hotkaps and 50 percent of the nearly 10,000 acres of strawberries is protected from frost damage with irrigation sprinkling. Only 2 percent of the tree-fruit acreage is subjected to heating[27] despite the high proportion of more sensitive deciduous tree fruits. Of the slightly more than 12-1/4 million trees of all ages reported in 1950 (42), only one-third of the total was apples, while cherries, accounted for 28 percent, peaches 29 percent, and pears, plums, and prunes 10 percent.

The 1950 United States Census of Agriculture (42) shows that, in Michigan, approximately 109,000 acres of vegetables is harvested for sale and 226,000 acres is planted in tree fruits. Thus, about 4,500 acres of orchards are subject to frost protection by heating, out of a total of more than 40,000 acres of crops on which frost-protection measures are employed.

Georgia and Alabama

In Georgia, where very little citrus fruit is grown, such frost protection as has proved practical has been mounding (1) to prevent injury to the base of the tree during freezes.[28] In the Fort Valley area, the peach growers make it a practice to have their land hard-packed and free of weeds by the time the orchards come into bloom, because it has been found that loose soil and cover crops greatly increase the frost hazard, especially in the peach orchards planted on fairly level land.[29] In Alabama heating satsuma trees to prevent freezing is considered impractical because all the freezes come before the blossoms appear.[30]

Virginia

A direct report was obtained from an important truck-crop area on the extent of frost-protection practices in the locality; this, combined with the data from United States Census of Agriculture (42) records and other general information, has given an insight into the probable need for heating and whether the practice may result in anything more than a marginal, irregular market for anthracite in this State.

According to the 1950 Agricultural Census (42), Virginia had about 211,000 acres in crops of the type for which some form of protection from frost damage may be required or justified. Of this, about 125,000 acres was in tree fruits, 82,000 in vegetables harvested for sale, and nearly 4,000 in strawberries. The value of

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[26] Letter from A. J. Bell, June 2, 1954.
[27] See footnote 26.
[28] Letter from F. E. Johnstone, Jr., June 6, 1952.
[29] Letter from E. F. Savage, Mar. 2, 1952.
[30] Letter from Otto Brown, June 23, 1952.

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crops from the total acreage was about $22-1/2 million in 1949, approximately one-half of the total value of the poultry and poultry products from this State in the same year.

Although at least one large grower is reported[31] to use orchard heaters, orchard heating has limited potential because of the extent to which orchard plantings are so located as to take advantage of the terrain favoring natural air drainage, just as in Pennsylvania. The vast bulk of plantings are in 21 counties in the rolling hills and mountains in the western part of the State, stretching in a band from Frederick, Clarke, and Loudoun Counties in the north, to Patrick, Carroll, Smyth, and Wise Counties in the southwest (42).

Of the nearly 6 million trees of all ages reported in 1950(42), apples made up 70 percent of the total, peaches 25 percent, and pears, cherries, plums, and prunes the remaining 5 percent.

Of the reported acreage (42) of vegetables harvested for sale, nearly two-thirds of the area cited above is in three Counties: Accomac, Northampton, and Princess Anne; these counties face the Atlantic Ocean and are subjected to a strong marine influence on weather and climate. The dollar value of the vegetables grown in these 3 counties in 1949 made up nearly two-thirds of the total of about $9-1/2 million for the State. The same counties had 80 percent of the strawberry acreage reported for the State, and produced about 85 percent of total value of strawberries grown in the State, which was over $1-1/3 million. Two of these Counties, Accomac and Northampton, are at the southern end of the thriving Delmarva Peninsula, which is referred to later in the discussion of significance of frost-protection measures in Maryland and Delaware.

In Accomac County, frost-protective measures have been employed to a very limited extent. Farmers have achieved a fair degree of success by using irrigation sprinkling, continuous aerial flights to stir the air, and Hotkaps. Since 1945, however, the percentage of planted acreage that has been subjected to frost protection in any given year has not been greater than 1 percent, or approximately 700 to 800 acres.[32]

In these three counties, where commercial growing of truck crops is concentrated and frost-protection practices may be justified, it appears that the need for protection is not great (though a more economical method might make it worthwhile) and, on the basis of the experience of Michigan and New Jersey growers and that cited for Accomac County, any current and near-future needs can be met, for the most part, by using methods other than heating. Only in the tree-fruit area does heating show any promise. However, with the infrequent need of orchard heating reported in Massachusetts and the low percentage in Michigan (where the proportion of tree fruits that are more sensitive to frost damage and bring higher returns is much higher than in Virginia), 2 percent of the orchard acreage in Virginia, or about 2,500 acres, seems a liberal estimate for the prospective area that might require more or less regular protection from frost damage each year.

Maryland and Delaware

In Maryland, the acreage of crops that might be considered as having a potential need for protection from frost damage, from time to time, amounts to about 129,000 acres on the basis of 1950 Census of Agriculture statistics (42). Of this acreage, 80 percent, or nearly 104,000 acres, was used to produce vegetables harvested for sale, with some 1,600 acres in strawberries, and the balance, less than 25,000 acres, in tree fruits of all kinds. Of the total value of vegetables harvested for sale, amounting to nearly $10 million according to the census figures, over 60 percent was supplied by the Eastern Shore counties, while metropolitan Anne Arundel and Baltimore Counties accounted for more than 17-1/2 percent.

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[31] Oral communication from P. S. Harner, 1952.
[32] Letter from J. G. Rogers, July 21, 1954.

Three counties on the southern end of the Eastern Shore, Somerset, Wicomico, and Worcester, supplied nearly 85 percent of the value of strawberries produced in the State. Nearly half of the total value of the tree fruits reported for the State were grown in Washington County, in the mountainous Appalachian area in northwestern Maryland. As in the experience cited previously for growers in Michigan and in the section on New Jersey, there can be little doubt that irrigation is probably the most effective and economic of the practical methods available for controlling frost damage to the bulk of the truck crops and strawberries grown in Maryland, which constitute the largest proportion of the acreage that might need occasional protection.

In Delaware, something over 45,000 acres is devoted to tree fruits, strawberries, and vegetables harvested for sale in New Castle, Kent, and Sussex Counties, according to the 1950 Agricultural Census records (42). More than 85 percent of this acreage is in vegetables, with over 90 percent of the reported total value, amounting to more than $3-1/2 million, being supplied by Kent and Sussex Counties to the south of metropolitan New Castle County. Nearly 100 percent of the more than 500 acres in strawberries is in Kent and Sussex. Conditions in these two counties are so much like those cited for Maryland in the preceding paragraph that the same comments regarding frost-protection measures apply here.

The Delmarva Peninsula, which consists of lower Delaware, the Eastern Shore counties of Maryland, and Accomac and Northampton Counties in Virginia, is a rich poultry-raising and truck-growing area. According to statistics compiled from the 1950 Census of Agriculture (42), the value of poultry and poultry products from Delmarva in 1949 exceeded $93 million. The total value of all tree fruits, vegetables harvested for sale, strawberries, and other small fruits from Delmarva the same year was just over $18 million, less than 20 percent of the value of poultry and poultry products. These comparative values emphasize the relative importance of supplying fuel for the regular heating of brooder houses each year in the year-round poultry business and supplying fuel for heaters to protect truck crops from frost damage for which the need is quite brief, very uncertain, and highly irregular.

New Jersey

Although New Jersey had more than 180,000 acres in fruits and vegetables, according to the 1950 Census of Agriculture (42), very little of this acreage is protected against frost.[33] Irrigation in peaches and blueberries to reduce frost injury at blossom time is used occasionally but by so few growers that the proportion is insignificant. The strawberry growers employ frost-protection measures more than any of the other agriculturists. On any night the temperature drops to freezing, the growers spray water over the plants with their portable irrigation systems until frost and ice are removed in the morning. It is estimated[34] that one-quarter of the strawberry acreage, which in the 1950 Census of Agriculture amounted to approximately 2,400 acres, may be irrigated for frost protection.

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[33] Letters from E. G. Christ, Apr. 24, 1952, and June 9, 1954.
[34] See footnote 33.

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The specific and often local character of the problem of controlling damage from frost is illustrated in southern New Jersey where frost-control practices are employed[35] to insure a satisfactory crop of holly berries in a 40-acre grove located in a frost pocket. Nearby small plantings on higher ground have required no artificial protection of tender new growth and blossoms during the spring to obtain an adequate crop of berries for Christmas holly cuttings. Two gasoline engine-driven wind machines (1 dual and 1 single unit) and oil-fired, hot-stack heaters within the grove, together with bonfires, using wood and old auto tires as fuel, along the borders of the grove are the means employed. Bonfires are commonly used along with the wind machines that have been used each spring since a single unit was put in service in 1948; however, the oil-fired heaters are used sparingly and only when conditions are more severe. These heaters require regular cleaning for good operation; stack maintenance is high, and they are considered dirty and messy to handle, refill, and empty.

Between 1948 and 1954, the wind machines were operated on as few as 4 nights in 1954 and as many as 15 nights in 1949, but the seasons of maximum and minimum hours of operation do not coincide, being 79 hours for the dual unit alone in 1949, its first year of operation, 84 hours for the single unit and 76-1/2 hours for the dual unit in 1951, the first year for this combination, and only 24 hours each for the single and dual machines in 1953. Upon arrival of the season when protection is likely to be necessary, it is imperative that the wind-machine engines and starting equipment be in near-perfect condition so that the units can be started on short notice without difficulty and will run without interruption. Otherwise, loss may be incurred on the final night of damaging temperatures in a season.

The earliest date for use of the wind machines in the 7 years covered was April 10 in 1949, the latest June 5 in 1950; however, the latest date for the first use of the wind machines in a season was May 8 in 1950; whereas the earliest date for their last use was May 12 in 1954. In general, the machines are started when the air temperature at the foot of the wind-machine tower reaches 33° to 35° F. In 1953 the shortest wind machine run was 2 hours long. The longest run of 10 hours in this season was on the night of April 21, when the heaters were fired at 8 p.m. (when the temperature had dropped to 30° F.) and firing was continued until 6 a.m. on April 22, to consume a total of 1,500 gallons of fuel oil; during this period the lowest temperature recorded in the grove was around 27° to 28° F. Each heater has a 10-gallon fuel-oil capacity and will burn about 10 hours on a single filling. Inversion temperature records taken from April 11 to June 3, 1949, showed the top of the 32-foot wind-machine tower to average 7° F. warmer than at ground level before starting the engines.

Although used each season since 1949, the oil-burning heaters were fired only 1 night each in the 1952 through 1954 seasons, on 2 nights each in 1949 and 1950, and on 4 nights in 1951, the season requiring the most protection in the 6 years for which both heater and wind machine records are available. The quantity of fuel oil consumed by the heaters ranged from a low of 527 gallons in 1952 to a high of 4,340 gallons in 1951, when 1,422 gallons of gasoline was burned by the dual and single wind machines (6 gallons per hour for each of 3 engines), the greatest quantity for any season thus far. During the other 6 years, gasoline consumption each season ranged from 432 gallons in 1953 for 24 hours' operation of the dual and single machines to 948 gallons in 1949 for 79 hours' running of the dual machine.

Because of dense foliage and thick growth, the shading effect (p. 10) is pronounced with holly when protection depends largely on heating with infrared radiant energy, which travels in straight lines from the source. In the older part of this grove where the trees were planted much closer than in the newer section, hot-stack and other high radiant output heaters used alone were found to protect only that side of the tree facing the heater. The other side received no protection, as evidenced later in the season by the absence of holly berries on the side away from the heat source.

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[35] Oral communication from D. F. Fenton, Dec. 29, 1954.

Massachusetts

The problem of frost protection in Massachusetts has received general appraisal (13), but orchard heating is not a common practice because it is only on rare occasions that this protection is necessary. Current estimates of the tree fruits and vegetables harvested for sale are about 15,000 and 35,000 to 36,000 acres, respectively. The acreage in tree fruits, other than apples, is relatively small and, so far as known, none of the vegetable acreage is heated to protect it from frost damage.36/ The 1950 Census of Agriculture records show cranberries were grown on an area of 11,000 acres, which is near the current acreage; no report on protective measures with this crop was obtained, but the demonstrated effectiveness of irrigation in protecting strawberries points to the probable success of the same or related practices in protecting cranberries, when necessary.

Conditioning of the surface layer of the soil in a plot of ground has been studied (21, 46). Tests showed that the direct application of 4,000 pounds of carbon black to the acre, mixed into the top 2 inches of a sandy loam, raised soil temperatures about 2° F. This may afford some protection and be a means of lengthening the growing season in colder areas, but, as a practical means of protection against frost damage at present market prices of carbon black, this method is out of the question (22). However, provided the practice is feasible, the use of pulverized anthracite may be economic because it is not only black and inert but, also, much lower in cost than carbon black.

New York

Although no published information on frost-protection practices in New York could be located, a sampling of several counties across the State typical of the areas where the bulk of fruit and truck crops potentially in need of protection are grown, along with a study of pertinent records from the 1950 United States Census of Agriculture, gives a picture of needs and practices, as well as prospects for heating as a practical means of frost protection in the State.

In this State, nearly 444,000 acres of crops potentially in need of protection from frost damage was in tree fruits, berries, and vegetables harvested for sale, as reported in the 1950 Agricultural Census (42). Slightly more than one-half of this acreage was in tree fruits and vineyards of all ages, about 47 percent in vegetables, and nearly 2-1/2 percent in berries. The combined value of these crops was approximately $68-1/3 million in 1949. Vegetables constituted nearly 55 percent of the value of the above total of truck and fruit crops, tree fruits just over 40 percent, with berries making up the remainder. The vast bulk of these crops was grown in the counties along Lake Erie, Lake Ontario, and the Finger Lakes, in the Hudson and Mohawk River Valleys, and on Long Island, all of which take advantage not only of local soil characteristics, but also of the tempering effects of the adjacent bodies of water. For example, in the Hudson River Valley, cherry plantings

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36/ Letters from O. C. Roberts and C. L. Thomson, June 4 and 8, 1954, respectively.

are confined to a somewhat narrower belt nearer the river than in the case of apples in order to get the tempering effect of the river on cold snaps in late spring (44).

Of the vegetables harvested for sale, 97 percent of their total 1949 value (42), approximating $37-1/4 million, was supplied by 38 counties, each of which raised over $100,000 worth. Over 82 percent of the total 1949 value was raised in 18 counties, mostly located along the lakes, in the Hudson and Mohawk River Valleys, and on Long Island.

Apples, worth over $17-3/4 million, made up about two-thirds of the 1949 total value (42) of tree fruits, of which 96 percent came from 25 counties. Over 70 percent of the value of the apples was produced in the 7 Counties of Columbia, Dutchess, Orange, Ulster, Niagara, Orleans, and Wayne, all located in the Hudson River Valley or along Lake Ontario. Of the more than $2-3/4 million worth of sour cherries in 1949 (42), 7 counties on the lakes and in the Hudson River Valley supplied over 90 percent. Sweet cherries, not so susceptible to frost damage as sour, had about 20 percent of the value of the sour variety.

Grapes, worth more than $3 million, were grown in 9 counties along the lakes and in the Hudson River Valley to make up 93 percent of the reported total value in 1949 (42). Chautauqua County, alone, located on Lake Erie, supplied nearly one-half of the total for the State. More than 85 percent of the nearly $2 million crop of peaches in 1949 were grown in 8 counties, all located along Lakes Erie and Ontario and in the Hudson River Valley (42). Three-fourths of the $3/4 million pear crop in 1949 was grown in 6 Counties: Columbia and Ulster in the Hudson River Valley and Niagara, Wayne, Orleans, and Oswego on Lake Ontario. Four counties, three on Lake Ontario and Ulster in the Hudson River Valley produced 70 percent of the nearly $1/2-million value in plums and prunes in 1949. Twelve counties produced nearly 80 percent of the slightly less than $3-1/2 million worth of berries (strawberries, raspberries, blackberries, dewberries, and other berries) in 1949 (42). Three Counties, Chautauqua and Erie on Lake Erie, and Ulster in the Hudson River Valley, produced over 52 percent of the berries. Of the $1-3/4 million worth of strawberries in 1949, 60 percent was produced in Chautauqua, Erie, Columbia, and Suffolk Counties.

In Nassau County on Long Island, more than $2-1/3 million value in vegetables was reported (42) as sold from about 6,800 acres harvested for sale in 1949. In this area, frost damage does not usually constitute a hazard, and no frost-protection measures are employed today except by some growers who have irrigation systems and who may use water as a frost deterrent. A few growers with roadside stands use Hotkaps, but this is the exception. Since 1945, less than 5 percent of the very early or late plantings have been protected against frost damage, and it is believed that no increase in frost-protection practices is likely unless the method is both practical and reasonable in price.37/ The vegetable acreage reported in 1949 showed a decrease of 40 percent from the nearly 11,500 acres in 1944 (42), and, today, production of vegetables in Nassau County has decreased about 75 percent since 1945 because the farms have been sold for building lots.38/ Some of this loss of production is, no doubt, being made up in neighboring Suffolk County, where the reported vegetable acreage (42) increased from about 12,900 in 1944 to more than 14,300 in 1949.

Frost-protective measures have received only a small amount of attention in Columbia County in the Hudson River Valley. In this county, the reported value of

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37/ Letter from H. H. Campbell, July 7, 1954.
38/ See footnote 37.

tree fruits, berries, and vegetables sold in 1949 was more than $2-1/2 million (42). It is estimated that 50 acres, at most, of tender vegetables like muskmelons, cucumbers, squash, and tomatoes is set in the field under Hotkaps in this county.[39] This acreage is about 13-1/2 percent of the acreage of the above-named vegetables grown in 1949 and less than 2 percent of the total acreage of vegetables harvested for sale, as taken from the 1950 United States Census of Agriculture (42). About 1946 there was a flurry of interest among fruit growers in protecting orchards against frost damage. A variety of methods were used, from spraying water on the trees to burning hay but, since then, very few have used frost-protection methods, although, in some years, frost losses are substantial. For example, the yield of grapes in 1954 was reduced because of frost damage at the time of blossoming.[40]

In Chautauqua County on Lake Erie, the combined value of tree fruits, berries, and vegetables harvested for sale was nearly $3-1/4 million in 1949, according to the census records (42), yet few, if any, frost-protection measures are employed in this area.[41] Grapes were the biggest single crop, being valued at $1-1/2 million in 1949. In the same year, raspberries made up over half the total value of small fruits and strawberries and raspberries together well over 90 percent of the total. Of the reported acreage of vegetables harvested for sale in 1949 (42), tomatoes accounted for about two-thirds of the total.

In this area, it is considered hazardous to set frost-sensitive crops, such as tomatoes, in the field before the middle of May, and the majority of the plants are set out the last week in May; however, a few early tomatoes are set under Hotkaps or tents in late April or early May, but these probably do not constitute more than 1 percent of the normal 4,000 to 5,000 acres of tomatoes for the area. With tree fruits and grapes, the major crops, no frost-protection measures are normally employed. Occasionally, when frosts are threatening late in May, a few growers will haul old grape posts, tires, baled hay, and other combustible materials into the orchards or vineyards and burn them, but this is done on only a small acreage. Furthermore, some question exists as to the value of this practice, but a fair appraisal is difficult because it is done on so few acres.[42]

This lack of interest across the State in frost-protection measures for tree fruits and vineyards, berries, and vegetables is due mainly to lack of need (except in occasional years); however, if a method is developed that is more effective, practical, and reasonable in cost, some growers could profit by frost protection.

Pennsylvania

According to the 1950 United States Census of Agriculture (42), there was some 253,000 acres in tree fruits, berries, and vegetables harvested for sale in Pennsylvania. Of this acreage, about 58-1/2 percent was in tree fruits and vineyards of all ages, 40 percent in vegetables, and the balance in strawberries and other berries. In 1949 these crops were valued at nearly $34 million, of which tree fruits made up 50 percent, vegetables about 47 percent, and berries 3 percent.

In 1949 apples, peaches, grapes, and cherries made up 97 percent of the total value of the tree fruits worth nearly $17 million. Apples, worth $10-1/3 million, accounted for more than 60 percent of the value of tree fruits (42); but, in Pennsylvania, this fruit is not ordinarily subject to significant damage from frost.

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[39] Letter from W. M. Barry, July 7, 1954.

[40] See footnote 39.

[41] Letter from T. D. Jordan, July 14, 1954.

[42] See footnote 40.

For example, at a large orchard in Lehigh County, less than 10 percent of the orchard acreage is in a low spot along a stream, where some frost damage is fairly common, yet 70 thousand bushels of apples was harvested from about 100 acres in a recent year despite noticeable frost damage.[43] The census figures (42) show that about 83 percent of the total 1949 value of apples came from 27 counties, each of which grew more than $100,000 worth; but, of these, 4 counties (Adams, Franklin, Berks, and Lehigh) each grew more than a half million dollars worth to make up 40 percent of the total.

Peaches, which are more susceptible to spring frost damage (and for which some frost-protection measures have been employed), were valued at $3.8 million in 1949; 6 southcentral and southeastern counties (Adams, Franklin, York, Lancaster, Berks, and Lehigh) accounted for 70 percent of the value of the crop. Approximately 90 percent of the $1.2 million worth of sweet and sour cherries in 1949 was raised in 3 counties (Adams, Franklin, and Erie), and over 90 percent of the more than $1 million worth of grapes was grown in Erie County (42).

Berries and small fruits in an amount worth a little over $1 million were harvested for sale from about 2,850 acres in 1949 (42). Of this total value, strawberries, potentially in need of some protection from spring frosts, made up 70 percent, raspberries 25 percent, and other berries 5 percent. However, because berries and small fruits in Pennsylvania are raised in scattered, relatively small acreages over a wide area, in contrast to other States cited in this survey, market promotion of anthracite for frost-control heating may require more effort than in those States where commercial growing is more concentrated. For example, in Pennsylvania, 27 counties produced about 73 percent of the total value of berries and small fruits in 1949; Erie and York Counties each produced over $85,000 worth of berries, the highest of any counties in the State, and only 5 out of the 27 counties harvested over $40,000 worth of berries each. In contrast, 12 counties in New York supplied 80 percent of the $3-1/2 million total value of berries and small fruits harvested in 1949. In the same year, 3 counties in Virginia supplied over 85 percent of the total of more than $1-1/2 million worth of strawberries harvested for sale.

Except for Erie County on Lake Erie and a few apple- and berry-growing counties in the extreme westcentral part of the State, the bulk of all fruits are grown in the southcentral and southeastern part of the State where the growing season generally begins earlier and continues later than in the plateau country to the northwest.

Vegetables harvested for sale and grown on more than 100,000 acres in 1949 had a total value of just under $16 million; 92 percent of this was accounted for by 31 counties, none of which grew less than $100,000 worth. Four counties (Bucks, Lancaster, Luzerne, and York) produced 53 percent, with Bucks County growing 30 percent (42).

In general, protection against frost damage by heating and using Hotkaps is a marginal practice in Pennsylvania, and irrigation sprinkling for the same purpose has been little used thus far.[44,45] A large orchard operator[46] in the southeastern part of the State has not considered heating because (1) he doubts that effective protection could be obtained economically (2) prolonged cold, wet weather in the spring is the more difficult problem; (3) most Pennsylvania orchards can take advantage of natural air drainage by proper location of plantings; and (4) heating is probably justified regularly only on the choicer and more expensive varieties of fruits. This agrees with recent experience cited earlier for increased heating in

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[43] Oral communications from J. E. Linde, Sr., and J. E. Linde, Jr., Dec. 2, 1952.
[44] Letter from C. S. Bittner, June 28, 1954.
[45] Letter from R. F. Fletcher, Aug. 18, 1954.
[46] See footnote 43.

Washington and with a similar observation made 25 years ago (1) namely, "In most Pacific-coast fruit districts the protection of pears, apricots, cherries, prunes, and almonds in the colder orchards is justified by the returns for the crops. The best paying varieties of apples also will justify protection costs, while the less popular varieties usually will not."

In Berks County, which lies south of Blue Mountain, peaches are heated, occasionally, in the spring; some growers burn old automobile tires for this purpose. Early sweet corn may warrant some protection along with berries but, on the whole, frost-protective measures receive little attention.[47] In Schuylkill County, which lies north of Blue Mountain, there have been scattered and irregular efforts to prevent frost damage. In the spring of 1954, two growers in the Hegins Valley area employed some heating; one burned old tires filled with sawdust in his peach orchard, the other had fires in a strawberry plot. At least 15 irrigation systems are installed in Schuylkill County, with the majority of them located in the Ringtown Valley, where one orchardist used his in the spring of 1954 in an attempt to protect apple blossoms. In none of these was there certainty that the frost-protective efforts were either necessary or beneficial. The late June 1954 forecast for a 90-percent fruit crop in the county reflected the lack of generally serious frost conditions earlier in the season; a year earlier, the forecast had been for a 60-percent crop.[48]

The Owner-operator of a small apple and cherry orchard in Centre County doubts that he could justify heating, and an orchardist in southcentral Pennsylvania, who had equipped his orchards with oil heaters, is reported to have been not too well satisfied because of oil leakage and the resulting damage to tree roots.[49]

In Bucks County, where nearly $5 million worth of vegetables was harvested for sale in 1949 from more than 20,000 acres (42), little has been done or is believed to be necessary to protect from frost damage. Spring frosts may damage early plantings of tomatoes, but it is not serious in this area because, normally, planting is not until about the time of the last frost, around May 8.[50]

This sampling of practices and possible needs in various counties where the bulk of fruits and vegetables are grown indicates that prospects for frost-control heating and the consequent need for fuel are not very significant, although a very small, irregular, and often uncertain, need does exist in scattered localities where a fruit grower could use some protection, occasionally, and may feel justified in equipping his orchard for heating.

Frost-Control Practices and the Future

In conclusion, it should be noted that the preceding discussion brings out the fundamental need for a practical and more economical method of protecting crops from frost damage, other than by heating, if frost-protection practices are to have anything more than marginal use, except under special circumstances.

Only in Washington was evidence obtained of increased use of heating to prevent frost damage, and this was largely attributable to increased plantings of fruits that bring a high return and to a cycle of colder seasons. In all other areas

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[47] Oral communication from J. F. Haldeman, July 6, 1954.
[48] Oral communication from C. I. Robertson, July 1, 1954.
[49] Oral communication from P. S. Harner, 1952.
[50] Letter from W. F. Greenawalt, July 7, 1954.

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studied, heating is on the decline because of high costs or is used only occasionally, if at all. In those instances where frost-control heating was said to be economical, and this usually was with high-return crops, the statement was qualified with the proviso that the number of firings be kept to a minimum.

In short, the prospective use of anthracite as frost-control heater fuel shows no signs of being more than a very small, marginal market and promises to be far more seasonal and far more dependent upon weather and climatic factors than the industrial-fuel market and the domestic, commercial, school, greenhouse, chicken-brooder, and similar heating markets. The quantity of fuel used in frost-control heating is determined on the basis of hours of use in a season, rather than days, weeks, or months, as with other types of heating.

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